

TOPEX/POSEIDON

Joint Verification Plan

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JOINT VERIFICATION PLAN (JPL)
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Pt. Arguello

CALIFORNIA

Pt. Conception

Platform
Harvest

Marettimo

SICILY

cnes

Lampione

Lampedusa

TOPEX/POSEIDON
Joint Verification Team

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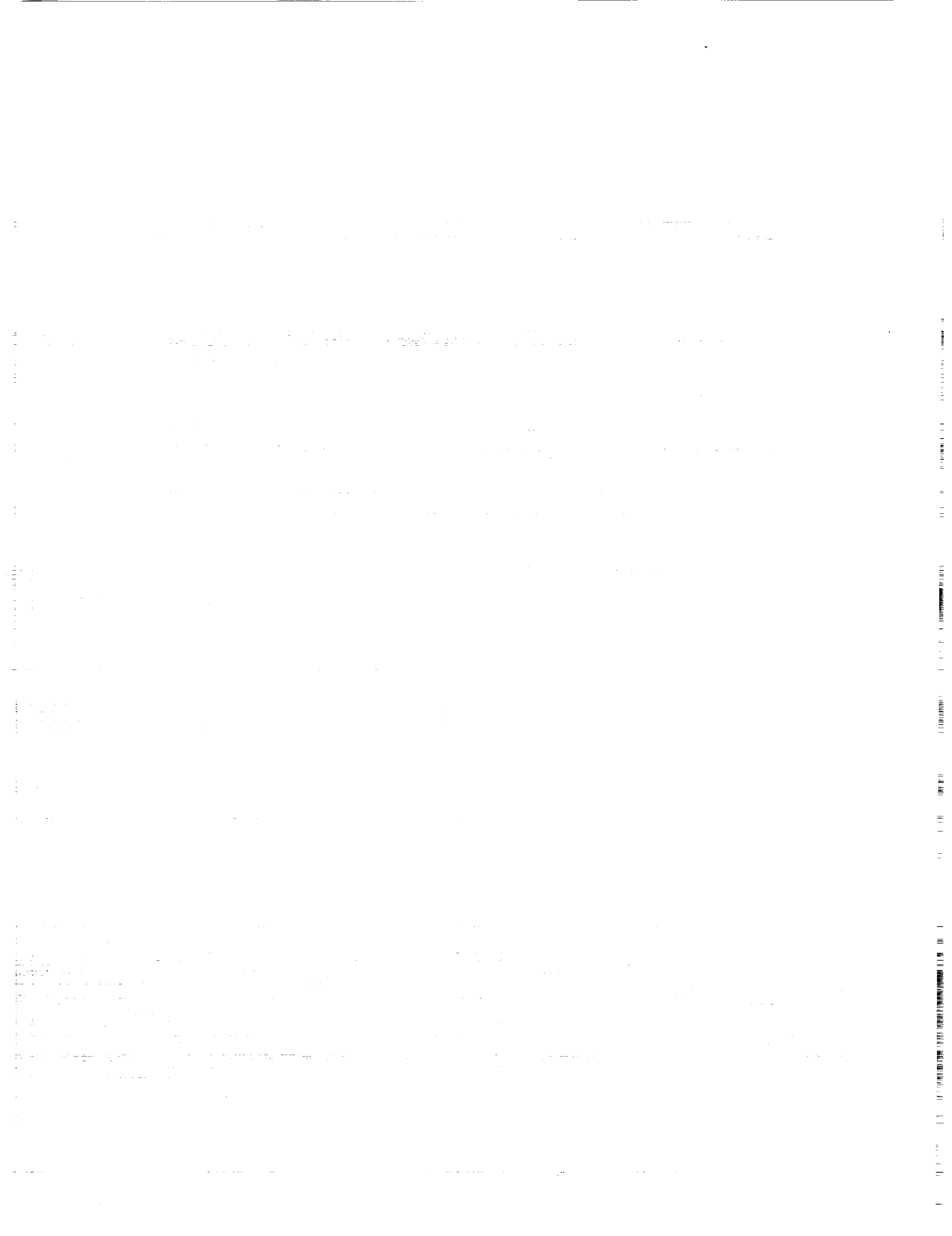
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Abstract

TOPEX/POSEIDON is a satellite mission that will use altimetry to make precise measurements of sea level with the primary goal of studying global ocean circulation. The mission is jointly conducted by the United States' National Aeronautics and Space Administration (NASA) and the French space agency, Centre National d'Etudes Spatiales (CNES). The current plans call for a launch of the satellite in August 1992. The primary mission will last 3 years, and provisions have been made to extend the mission for an additional 2 years. The mission has been coordinated with a number of international oceanographic and meteorological programs, including the World Ocean Circulation Experiment and the Tropical Ocean and Global Atmosphere Programme, both of which are sponsored by the World Climate Research Programme. The observations of TOPEX/POSEIDON are timed to provide a global perspective for interpreting the in situ measurements collected by these programs and in turn will be combined with observations of other satellites to achieve a global, four-dimensional description of the circulation of the world's oceans.

In the autumn of 1987, an international team of 38 Principal Investigators was selected to participate in the mission. These scientists have been working closely with the TOPEX/POSEIDON Project to refine the mission design and science plans. During the first 6 months after launch, a number of these investigators will join with the project to conduct a wide range of oceanographic and geophysical investigations using the TOPEX/POSEIDON data. The purpose of these investigations is to demonstrate the scientific utility of the mission to the international scientific community. This document details the plans developed by this team of investigators, referred to as the TOPEX/POSEIDON Joint Verification Team, as well as a summary of the major elements of the mission.



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I. Introduction

This TOPEX/POSEIDON Joint Verification Plan (JVP) describes the activities of the Joint Verification Team (JVT), which consists of members of the project and the science working teams. The JVP will focus primarily on the intensive verification phase of the mission; some of the activities, however, are planned to continue over the life of the mission.

Section I provides background information about the TOPEX/POSEIDON Mission and an overview of verification. A technical overview of verification is given in Section II. Section III is focused specifically on the American plans and Section IV on the French plans for instrumenting two verification sites, one in the Pacific and the other in the Mediterranean. Plans submitted by investigators interested in supporting verification are described in Section V. Section VI details the data analysis and distribution plans that support joint verification.

A. Mission Overview

1. Background

TOPEX/POSEIDON is a satellite mission that will use altimetry to make precise measurements of sea level; the primary goal is study of global ocean circulation. The mission is jointly conducted by the United States' National Aeronautics and Space Administration (NASA) and the French space agency, Centre National d'Etudes Spatiales (CNES). The current plans call for a launch of the satellite in August 1992. The background for the early phase of the development of the mission is given in Born et al. (1984). The material in this section provides an updated overview of the mission as it is currently configured.

The primary mission will last for 3 years, with the possibility of an extended mission for an additional 2 years. The mission has been coordinated with a number of international oceanographic and meteorological programs, including the World Ocean Circulation Experiment (WOCE) and the Tropical Ocean and Global Atmosphere Programme (TOGA), both of which are sponsored by the World Climate Research Programme (WCRP). The observations of TOPEX/POSEIDON are timed to provide a global perspective for interpreting the in situ measurements collected by these programs, which in turn will be combined with satellite observations to achieve a global, four-dimensional description of the circulation of the world's oceans.

The utility of a satellite altimeter system for ocean circulation studies has been demonstrated by three previous missions: GEOS-3 (Stanley, 1979), Seasat (Born et al.,

1979), and Geosat (Douglas and Cheney, 1990). However, none of these missions was optimally designed for ocean circulation studies, especially for ocean variabilities at the basinwide scales that are most difficult to observe using shipboard techniques and yet bear significantly on global change. The main thrust of TOPEX/POSEIDON will be to achieve a substantial increase in our knowledge of large-scale ocean circulation through an optimized measurement system.

In the autumn of 1987, an international team of 38 Principal Investigators was selected to participate in the mission. These scientists have been working closely with the TOPEX/POSEIDON Project in refining the mission design and science plans. After launch, they will conduct a wide range of oceanographic and geophysical investigations using the TOPEX/POSEIDON data and demonstrate the scientific utility of the mission to the international scientific community.

The planning and implementation of the mission are being conducted jointly by the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA, and Centre Spatial de Toulouse, the technical center of CNES. The various sensors have been integrated into a spacecraft designed and built by Fairchild Space, under contract with the Jet Propulsion Laboratory.

2. Sea Level From Space

A satellite altimeter system employs two techniques to arrive at sea level: radar altimetry and precision orbit determination. Radar altimetry is the precise measure of the satellite's altitude above the ocean surface. Precision orbit determination is the measure of the satellite's orbital distance from the center of Earth. The difference between these two measurements is the height of the sea surface relative to the center of Earth. This height is called sea level, which is the primary measurement of the mission. In addition to sea level, ocean wave height and wind speed can also be measured from the shape and strength, respectively, of the altimeter's return pulse.

To make useful observations of the large-scale ocean currents, sea-level measurements with an accuracy of a few centimeters over spatial scales of hundreds to thousands of kilometers are required. Achieving this level of accuracy with a spaceborne altimeter is a great challenge that involves the reduction of errors from a variety of sources, including the altimeter instrument, the determination of the satellite orbit, range delay of the radar pulse in the atmosphere, and the interaction of ocean waves with the

radar pulse. Additionally, sea-level variabilities caused by ocean and solid-earth tides can also interfere with the sea-level signatures of ocean circulation and must be removed from the sea-level data.

The principal goal of TOPEX/POSEIDON is to measure sea level with unprecedented accuracy such that small-amplitude, basinwide sea-level changes caused by large-scale ocean circulation can be detected. To reach this goal, the sensor system and orbit for the mission have been optimally designed.

3. The Sensors

There are six science instruments in the mission payload (see Figure I-1), four from NASA and two from CNES. They are divided into operational and experimental sensors as follows:

(1) Operational Sensors.

- (a) Dual-Frequency Radar Altimeter (ALT) (NASA).
- (b) TOPEX Microwave Radiometer (TMR) (NASA).
- (c) Laser Retroreflector Array (LRA) (NASA).
- (d) Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS) Dual-Doppler Tracking System Receiver (CNES).

(2) Experimental Sensors.

- (a) Single-Frequency Solid-State Radar Altimeter (SSALT) (CNES).
- (b) Global Positioning System Demonstration Receiver (GPSDR) (NASA).

The ALT, operating at 13.6 GHz (Ku-band) and 5.3 GHz (C-band) simultaneously, is the primary instrument for the mission. The measurements made at the two frequencies will be combined to obtain precise altimeter height measurements over the oceans of the world. These measurements will be corrected to first order for errors caused by ionospheric free electrons, of which the total content will be obtained as a by-product of the measurement. This instrument is the first spaceborne altimeter that uses two-channel measurements for ionospheric range corrections.

The TMR will use the measurement of sea-surface microwave brightness temperature at three frequencies (18 GHz, 21 GHz, and 37 GHz) to estimate the total water-vapor

content in the atmosphere along the beam of the altimeter; this estimate will correct errors in the altimeter measurement that result from this source. The 21-GHz channel is the primary channel for water-vapor measurement. The 18-GHz and 37-GHz channels are used to remove the effects of wind speed and cloud cover, respectively, in the water-vapor measurement.

The LRA will be used with a network of 10 to 15 satellite laser ranging stations (Figure I-2) to provide the NASA baseline tracking data for precision orbit determination and calibration of the radar altimeter bias. The DORIS tracking system will provide the CNES baseline of tracking data using microwave Doppler techniques for precision orbit determination. The DORIS system has been successfully demonstrated by the SPOT-2 Mission. The system is composed of an onboard receiver and a network of 40 to 50 ground transmitting stations (Figure I-3), providing all-weather, global tracking of the satellite. The signals are transmitted at two frequencies (401.25 MHz and 2036.25 MHz) to allow removal of the effects of ionospheric free electrons in the tracking data. Therefore, the total content of the ionospheric free electrons can also be estimated from the DORIS data and used for the ionospheric correction for the SSALT.

The two experimental instruments are intended to demonstrate new technology. The GPSDR, operating at 1227.6 MHz and 1575.4 MHz, will use a new technique of GPS differential ranging for precise, continuous tracking of the spacecraft with better than decimeter accuracy. The SSALT, operating at a single frequency of 13.65 GHz, will validate the technology of a low-power, low-weight altimeter for future Earth-observing missions. It will share the antenna used by the ALT; thus only one altimeter will operate at any given time.

4. Orbit Selection and Determination

The orbit enters into the measurement of sea level in two important ways. It dictates the temporal and spatial sampling pattern of the altimeter, which in turn dictates our ability to measure certain sea-surface features. In addition, because it supplies the reference for the altimeter measurement, the orbit enters directly into the computation of sea level; therefore, our knowledge of the radial component of the orbit, as obtained through the process of orbit determination, is of great importance.

For a single satellite mission, temporal resolution and spatial resolution are in competition: the higher the temporal resolution, the lower the spatial resolution, and vice versa. In addition, sea-level changes due to ocean and earth tides must be properly removed from altimeter

measurements before they can be used to study ocean circulation. The inclination of the mission's orbit, which is 66.0 deg, has been selected to avoid sampling the tidal signals at undesirable frequencies such as semiannual, annual, and zero frequencies (fixed biases). The precise sea-level measurements made by the mission at a set of aliased tidal frequencies can be used to improve the knowledge of tides and consequently to remove tides from the sea-level measurement. A repeat period of 10 days (127 revolutions) has been selected as a compromise that takes temporal resolution, spatial resolution, and tidal aliasing into consideration. This choice results in an equatorial cross-track separation of 315 km.

To maximize the accuracy of orbit determination, a high-altitude orbit is preferred because of the reduced atmospheric drag and the reduced gravity perturbations acting on the satellite. The height of the orbit is limited by the increased power needed by the altimeter to achieve the required signal-to-noise ratio. A compromise is in the range of 1200 to 1400 km. Within this range, the exact altitude that allows the orbit to satisfy all other constraints and fly over the two verification sites (Point Conception off California and Lampedusa Island in the Mediterranean Sea) is 1336 km. Shown in Table I-1 are the characteristics of the baseline mission orbit.

Since the satellite orbit tracking provided by the laser ranging and DORIS is not continuous in time, orbit determination based on dynamical equations is required to produce a continuous, precise orbit for the mission. To achieve the expected 13-cm (rms for a single pass) orbit accuracy for the mission, the knowledge of Earth's gravity field must be significantly improved. Precision-orbit-determination teams have been established by both NASA and CNES to accomplish this task. Because orbit error is the most significant error for the sea-level measurement (see Table I-2), a long-lead prelaunch effort has been made by these teams to develop a much improved model for Earth's gravity field, which will be used for the orbit determination.

A hierarchy of progressively improved models has been produced by this effort (e.g., Marsh et al., 1988 and 1990). After launch of the satellite, these teams will use the satellite tracking data to further "tune" the gravity model to optimize it for the mission. Knowledge of the spectral characteristics of the remaining orbit errors will be used by the Principal Investigators for further improvement of the orbit accuracy.

5. Antenna Sharing Plan

In accordance with the TOPEX/POSEIDON Memorandum of Understanding (1987), the CNES (POSEIDON) altimeter must share an antenna with the

NASA (TOPEX) altimeter and will operate for relatively short periods during the verification phase of the mission. Therefore it is important that use of the CNES altimeter be allocated effectively. The key elements of intense verification are the calibration and cross-calibration of the two altimeters, the evaluation of bias drift, and the calibration of the NASA ionosphere correction and the CNES ionosphere model. A project-approved antenna-sharing plan that has taken these elements into consideration has been adopted and is summarized below.

The antenna-sharing plan is based on a repeated pattern consisting of a set of five 10-day cycles (see Figure I-4). The pattern begins once the satellite is in the repeat orbit. For the first 10-day cycle, the CNES altimeter will be on for approximately 2 days, the first day (passes 18 through 44) as it overflies the NASA verification site on pass 43 and the second day (passes 220 through 246) as it overflies the CNES verification site on pass 222. On the second 10-day cycle, the NASA altimeter will be on continuously. By the end of the second 10-day cycle, each altimeter will have overflown the NASA verification site and the CNES verification site once.

Near the end of the third 10-day cycle, the CNES altimeter will begin a 3-day subcycle, starting with pass 220. The subcycle ends early in the fourth cycle with pass 44. The CNES altimeter will pass over the CNES verification site during this 3-day subcycle. The 3-day subcycle will provide a global set of data as the ground track completely circulates Earth. This data set will be used for global crossing-arc and repeat-track analyses and the analysis of the ionosphere correction. This set of ground tracks will also be used to cross-calibrate the NASA and CNES altimeters.

On the fifth 10-day cycle, the CNES altimeter will be on for approximately 1 day (passes 220 through 246) as it overflies the CNES verification site. After completion of this 10-day cycle, the five-cycle pattern will repeat throughout the verification phase of the mission.

With this plan, the CNES altimeter will be on 12% of the time. For three out of five passes over the NASA verification site, the NASA altimeter will be on. The same is true for the CNES altimeter with three out of five passes over the CNES site.

B. Verification

1. The Expected Performance

Based on the expected performance of the instruments and orbit determination, an attempt has been made to estimate the error budget for the TOPEX/POSEIDON

altimetry system (Table I-2). Determination of the uncertainty in the instruments and the integrity of the science data is a continuing process that involves participation of both the project teams and the Principal Investigators. However, during the first 6 months of the mission, an intensive verification campaign will be conducted jointly by NASA and CNES to calibrate and verify satellite measurements of geophysical parameters against in situ data from two verification sites. In addition, satellite laser ranging and DORIS data will be used to validate precision orbit determination and to tune the gravity field model that will be used during the Observational Phase of the mission.

2. On-Site Verification

NASA will instrument an oil platform (Platform Harvest) 19.5 km west of Point Conception, California, to obtain data on sea level and related parameters. Sea-level measurements will be made by an acoustical device and pressure gauges mounted on the oil platform. The sea-level data along with laser data and Global Positioning System (GPS) survey data from nearby tracking sites will be used to determine the distance between the satellite and the sea surface; this distance will then be compared with the altimeter range measurement to determine the altimeter bias and bias drift. Other instrumentation at the oil platform will include a GPS receiver for station positioning and calibration of the total electron content, a surface pressure gauge for the dry-troposphere correction, and an upward-looking water-vapor radiometer (WVR) for the wet-troposphere correction. In addition to instrumenting the platform, the current plan calls for the deployment of two other upward-looking WVRs at two widely separated locations to independently calibrate the TMR measurement.

CNES will instrument a small islet, Lampione, located 18 km west of Lampedusa Island in the Mediterranean Sea. The minimum instrumentation configuration includes a laser on Lampedusa, a tide gauge on Lampione, two tide gauges on Lampedusa, one deep-sea pressure gauge between the two islands, a DORIS station on Lampedusa, and two ground-based radiometers, a meteorological station, and two GPS buoys. These instruments will be used to verify sea level, atmospheric pressure, wind speed, wave height, water vapor, electromagnetic bias, wave skewness, and precision orbit determination. Ionospheric corrections will be verified by comparison of DORIS and GPS measurements with the ALT-derived ionospheric corrections and with data from the European Incoherent Scatter Radar System (EISCAT).

3. Joint Verification

The principal objective of joint verification is to assess the performance of the TOPEX/POSEIDON measurement system, which includes the altimeter and orbit-determination subsystems. The general approach is to pool the talents and resources of the project and science teams to form a Joint Verification Team (JVT). Investigators from programs outside of TOPEX/POSEIDON have also been invited to contribute. The JVT will participate in the evaluation of the measurement system and will report its plans and findings at prelaunch and postlaunch JVT meetings organized jointly by NASA and CNES. These meetings are intended to provide a forum for the science community to share and discuss its results with the other project personnel. Approximately 5 months after launch, the JVT will summarize its assessment of the measurement system and make specific recommendations to the project for improvements, if any, to the Geophysical Data Records (GDRs) prior to routine distribution of the GDRs.

Table I-1. Characteristics of the operational orbit.

Parameter	Symbol and value
Mean elements	
Semimajor axis, km	$a = 7714.4278$
Eccentricity	$e = 0.000095$
Inclination, deg	$i = 66.039$
Inertial longitude of ascending node, deg	$N = 116.5574$
Argument of perigee, deg	$w = 90.0$
Auxiliary data	
Reference equatorial altitude, km	$h = 1336$
Nodal period, s	$P = 6745.72$
Cycle (127 revs) period, days	$T = 9.9156$
Inertial nodal rate, deg/day	$W = -2.0791$
Longitude of equator crossing of pass 1, deg	$I = 99.9242$
Acute angle of equator crossing, deg	$x = 39.5$
Ground-track velocity, km/s	$v = 5.8$

Table I-2. Estimated error budget for TOPEX and POSEIDON measurements of sea level.

Error source	TOPEX component, cm	Decorrelation distance, km	POSEIDON component, cm
Altimetry			
Instrument noise	4.1 ^a	6	2.0
Bias drift	2.0	>>10,000	1.7
Media			
EM-bias	2.0	50 to 1000	2.8
Skewness	1.0	50 to 1000	
Troposphere, dry	0.7	1000	0.7
Troposphere, wet	1.2	50 to 1000	1.2
Ionosphere			2.0
Orbit			10.0
Gravity	10.0	10,000	
Radiation pressure	6.0 ^b	>10,000	
Atmospheric drag	3.0	>10,000	
GM (gravitational constant for mass of the Earth)	2.0	10,000	
Earth and ocean tides	3.0	10,000	
Troposphere	1.0	10,000	
Station location	2.0	10,000	
RSS absolute error	13.7		10.8

Major Assumptions for TOPEX:

1. Dual-frequency altimeter.
2. Three-frequency radiometer.
3. Fifteen laser tracking stations.
4. Altimeter data averaged over 1 s.
5. $H_{1/3} = 2$ m; wave skewness = -0.
6. Tabular corrections based on wave-form tracker comparisons.
7. 1300-km altitude.
8. No anomalous data, no rain.
9. Improved prelaunch gravity field; adjustment postlaunch.
10. ± 3 mbar surface pressure from weather charts.
11. 100-ms spacecraft clock.

Major Assumptions for POSEIDON:

1. Single-frequency altimeter.
2. Altimeter data averaged over 1 s.
3. $H_{1/3} = 2$ m; $\sigma_0 = 10$ dB.
4. The instrument noise and drift estimates result from simulations and flight-model ground tests (Raizonville et al., 1991).
5. The EM bias and skewness error result from crossover analysis (Gaspar, 1990).
6. The troposphere wet error is deduced from the TMR error estimate.
7. The ionosphere error is deduced from the DORIS-based correction (Escudier et al., 1991).
8. The radial orbit error includes all the error sources and is deduced from the DORIS/SPOT2 experiment (Laudet, 1991).

^aIncluding the noise in the ionospheric correction by the dual-frequency altimeter measurements.

^bSolar, Earth, and thermal radiation.

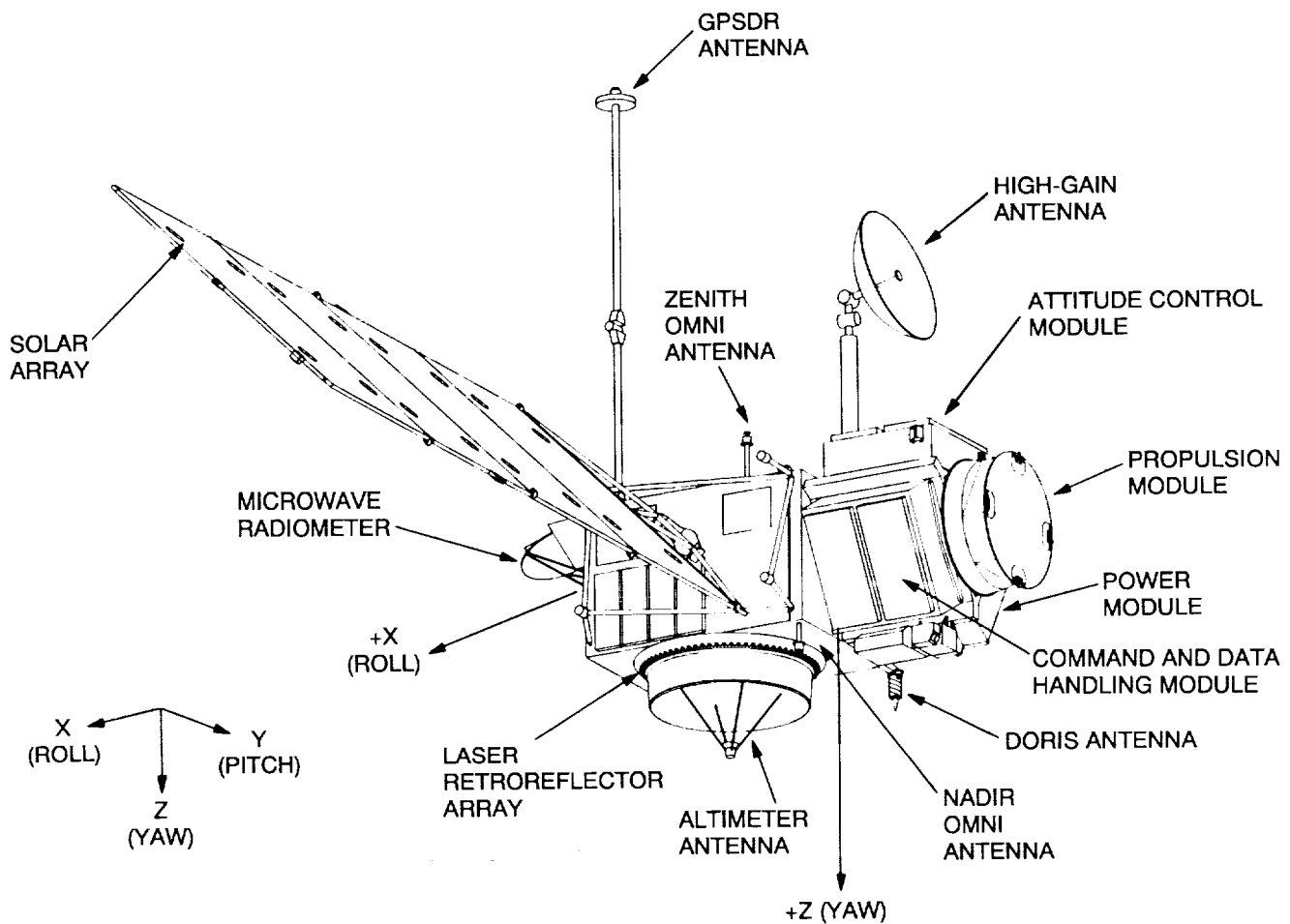
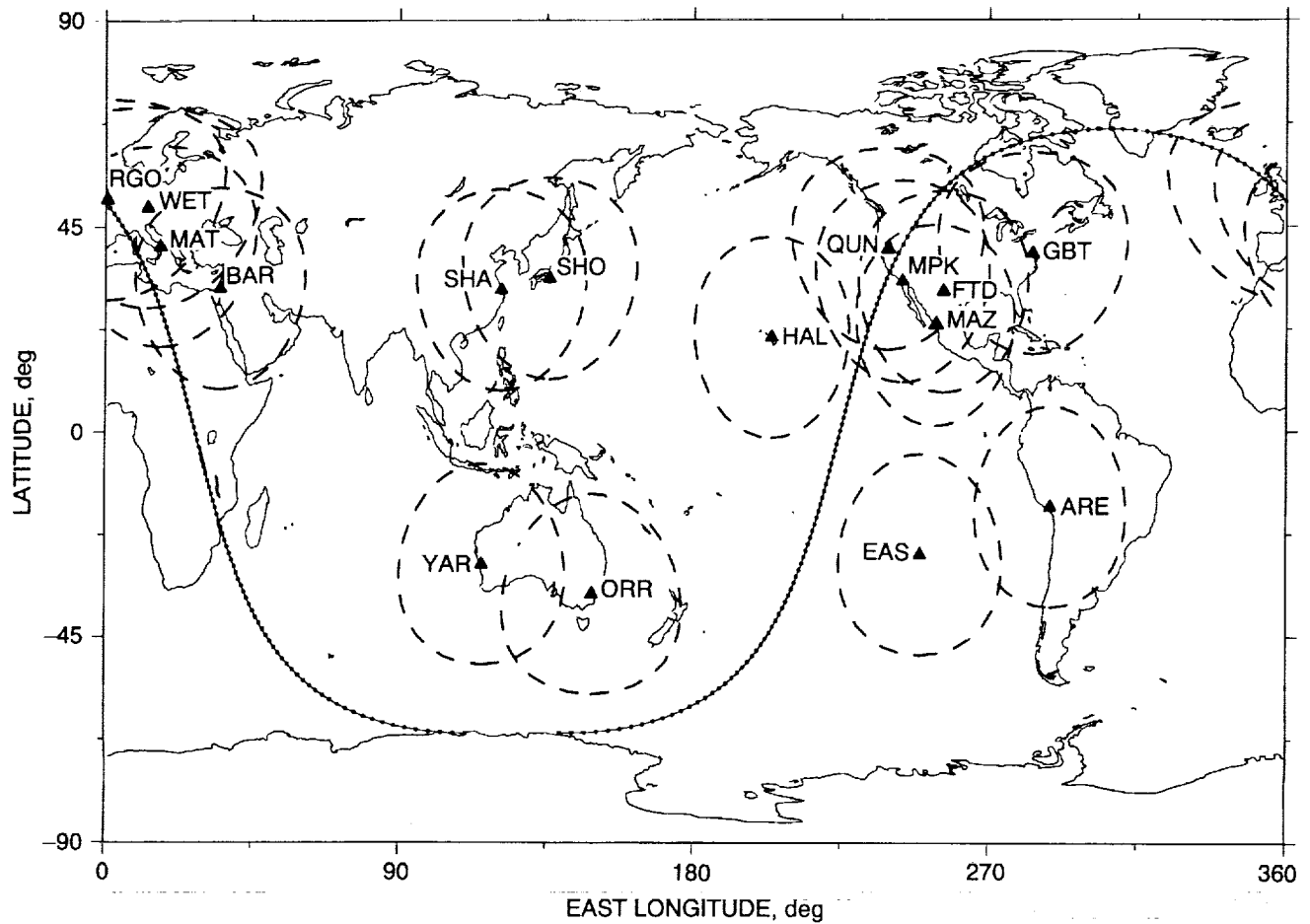


Figure I-1. Satellite configuration (deployed).



ARE	Arequipa, Peru	MPK	Monument Peak, California
BAR	Bar Giyyora, Israel	ORR	Orroral Valley, Australia
EAS	Easter Island	QUN	Quincy, California
FTD	McDonald Observatory (Fort Davis), Texas	RGO	Royal Greenwich Observatory, Great Britain
GBT	Greenbelt, Maryland	SHA	Shanghai, China
HAL	Mt. Haleakala, Hawaii	SHO	Simosato, Japan
MAT	Matera, Italy	WET	Wetzell, Germany
MAZ	Mazatlán, Mexico	YAR	Yarragadee, Australia

Figure I-2. Global laser coverage for TOPEX/POSEIDON.

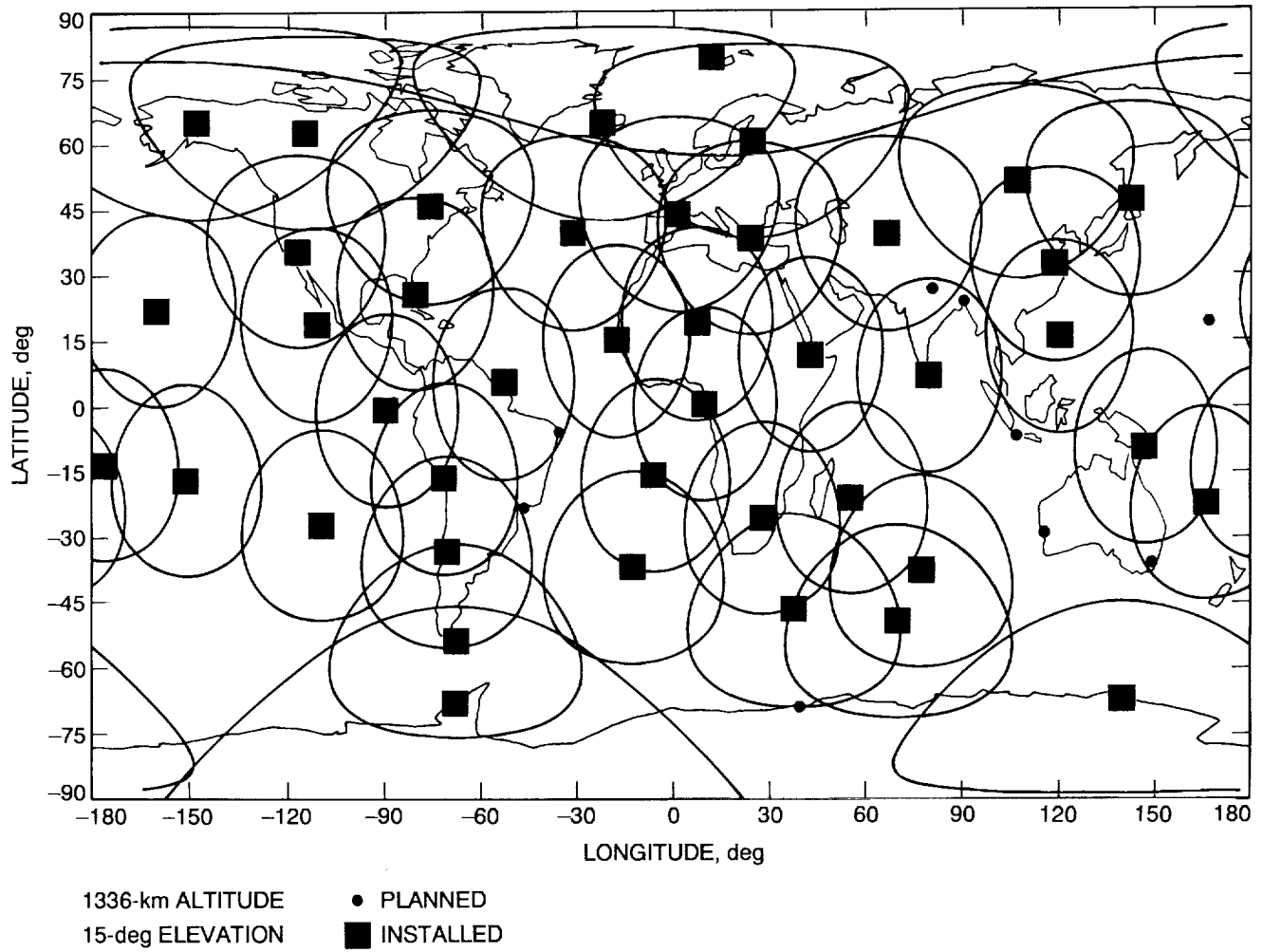


Figure I-3. DORIS orbit-determination beacons for TOPEX/POSEIDON.

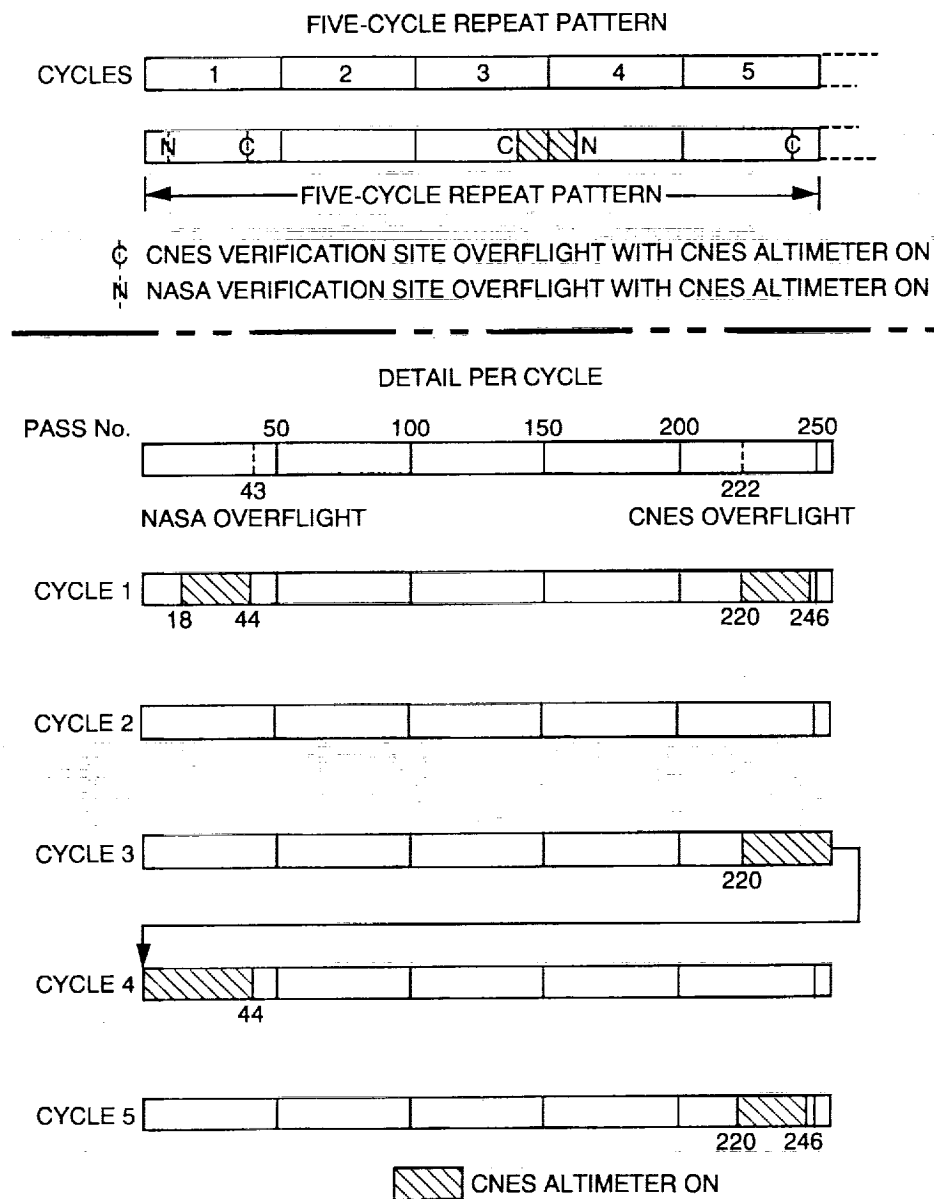


Figure I-4. Antenna sharing schematic for altimeter verification.

II. Technical Overview of Joint Verification

A discussion of the philosophical approach and the general techniques that will be used for TOPEX/POSEIDON verification is given in this section.

A. Figures of Merit

To properly interpret the data obtained from TOPEX/POSEIDON, it is important to understand the spectral characteristics of the measurement error. For the purposes of verification, we consider the figures of merit commonly used to describe the performance of a measurement system: the noise, the absolute error (bias), and the stability (bias drift). The importance of any one of these figures of merit is, of course, subjective. For example, the noise level is critical to studies of small-scale features, whereas bias drift is much more relevant to studies of ocean circulation. A number of techniques will be used throughout the mission to isolate and examine a variety of error sources. The discussion presented here provides an overview of some of these techniques in terms of the fundamental figures of merit mentioned above.

1. Noise

Random noise has been the figure of merit most often associated with altimeter performance and, perhaps for this reason, has generally been accepted as being of fundamental importance. Noise, if large enough, can have adverse effects on sea-surface variability and ocean-circulation studies. Prior to launch, estimates of instrument noise will be obtained from theoretical design considerations and controlled laboratory tests. However, it is important to understand the noise characteristics of the measurement system once it is in an operational environment.

Once on orbit, the altimeter noise will be calibrated either by performing polynomial (quadratic) fits directly to small batches of altimeter data or by examining the power spectral density derived from a Fourier analysis of the altimeter data. The dependence of the monotonic increase in altimeter noise with $H_{1/3}$ will be quantified by this analysis, where care will be taken to assure that the data set under examination is representative of the global ocean.

The noise figure for the NASA altimeter will simply be a combination of the system noise from the K-band and C-band channels. The NASA altimeter uses these two channels to directly correct for the path delay due to the ionosphere, whereas CNES uses a modeling technique based on DORIS data. For the purposes of comparison, then, the

noise for the CNES altimeter can be considered to be a combination of instrument noise and a quasi-random error resulting from the unmodeled variability of the ionosphere. This error can best be quantified by comparing the NASA altimeter data with the ionosphere model. Other techniques that will be used include the comparison of NASA and CNES altimeter data with GPS and DORIS data. A thorough analysis of errors due to the ionosphere is expected by the end of the verification phase of the mission. This analysis will continue over the course of the mission to monitor the relative drift between the K-band and C-band channels.

2. Bias

Using the on-site verification techniques described in this plan, we expect to obtain an estimate of the bias for each altimeter at the 2- to 4-cm confidence level after about three or four successful passes. A significantly more accurate estimate of the bias will not be obtained until many months into the mission. Fortunately, there is no immediate demand for an accurate estimate of the bias, though it will eventually be needed to relate TOPEX/POSEIDON data to extant and future data sets.

A cross-calibration of the bias between the CNES altimeter and the NASA altimeter can be obtained by analyzing data on the same set of fixed repeat tracks. Such a set of repeat tracks has been defined and is discussed in the Antenna Sharing Plan (Subsection I.A.5.). There is also the potential of obtaining a relative bias determination by examining data at the crossing points of the TOPEX/POSEIDON and European Remote Sensing (ERS-1) satellites. A bias introduced by a bias between the NASA K-band and C-band altimeters (i.e., a bias in the ionosphere correction) will be resolved by analyzing dual-frequency data from DORIS or GPS.

3. Bias Drift

As mentioned above, the performance of an altimeter is often described in terms of its noise; however, when considering the ultimate objectives of the project, it is the possibility of an insidious bias drift that is of most concern. A sizeable bias drift, say on the order of 1 to 2 cm in 10 days, will be detrimental to the ocean circulation experiment. Even a subtle bias drift, say on the order of 1 to 2 cm a year, will have serious consequences for global-change studies. Therefore, it is of the utmost importance that the drift characteristics of the altimeters be understood early in the program.

The most expedient means for recovering a drift is through crossing-arc and repeat-track analyses. These techniques rely on the strength of the statistics of large numbers. The data are gathered along a fixed set of repeat tracks that, by design, maximize the number of observations of the ocean's permanent topography. This tends to make temporal signals appear as quasi-random errors; therefore, a relatively small secular trend (~ 1 cm/yr) in the altimeter system should be detectable. The data gathered at the verification sites can be used to determine bias drift as well, but only over the long term. Indeed, a number of different techniques are needed to isolate altimeter drift from drifts in the verification system itself.

The key to recovering bias drift is to reduce systematic orbit errors and variable sea-surface features to small, random, or nearly random, errors. To reduce orbit errors, we must reduce gravitational and nongravitational modeling errors. Highly accurate and extensive satellite tracking systems are also essential to reducing orbit error. Significant effort has been directed toward improving orbit-determination models and providing TOPEX/POSEIDON with the best tracking systems available (i.e., Satellite Laser Ranging (SLR), DORIS, and GPS).

Crossing-arc and repeat-track analyses will make use of precision orbits based on at least 10 days of tracking data. With SLR, the orbit will be sparsely tracked over much of the globe. As a result, estimates of sea level will be susceptible to gravitational and nongravitational modeling errors in these regions. It is noted that the more continuous coverage obtainable with DORIS and GPS will mitigate this problem somewhat. Geographically fixed errors, which are attributable to the gravity model, are not of particular concern. When it comes to monitoring bias drift, systematic temporal errors are the problem. Stochastic errors due to changing tracking configurations and orbit-Sun geometry introduce error signatures over spatial scales greater than 2000 km and on temporal scales greater than 10 days. Some of this error will be removed by estimating a spatial tilt and bias introduced by the orbit over each of the repeat tracks. The trends and statistics of the bias gathered for each of the repeat tracks around the globe can then be used to calibrate the drift in the altimeter system.

When conducting such analyses, it is important to properly deal with the variable oceanic signal. The power spectrum of the ocean is represented in Figure II-1. In a statistical sense, the signal is less than a decimeter on scales greater than a few hundred kilometers. Smaller scale features, such as eddies, will be on the order of many decimeters. If these features are ignored in the repeat-track and crossing-arc

analyses, one can arrive at erroneous conclusions. Other oceanic signals, such as those due to weather and tides, will contribute further to the apparent noise level. In total, the signal introduced by sea-surface variability can be expected to be on the order of a decimeter. As with the orbit error, an error in bias drift resulting from temporal sea-surface variability will be significantly reduced through the strength of large numbers.

B. Verification of Media Corrections

Throughout this discussion it has been inferred that the bias, bias drift, and noise in the measured sea level come only from the altimeter. In practice we know that they may originate in any part of the measurement and verification system (e.g., the altimeter, TMR, WVRs, and tide gauges). Therefore, a significant amount of effort will be directed toward isolating various error sources. Some of the techniques for doing so will be addressed below in terms of the media effects listed in the error budget given in Table I-2.

1. EM-Bias

When an electromagnetic pulse from an altimeter reflects from the surface of the ocean, it is scattered in such a way that it appears to return from a surface that is slightly depressed relative to the mean sea surface. This phenomenon has come to be known as electromagnetic bias (EM-bias). It is generally accepted that EM-bias depends on wave height and perhaps wind speed; therefore, it would be meaningful to assess $H_{1/3}$ and α_0 over a wide range of sea states and wind speeds. This will be accomplished by comparing altimeter data with wind and wave buoy data gathered at sites of opportunity and with meteorological models. Owing to the abundance of ocean scenes with 2- to 3-m sea states, verification of $H_{1/3}$ over this portion of the range will be possible early in the mission. At least 6 to 8 months of data will be needed to assess $H_{1/3}$ over the full range. This is based on the assumption that launch will take place near the middle of northern summer and the fact that there are relatively few wind and wave buoys in the southern oceans.

EM-bias will be inferred by observing correlations between sea-level and sea-state data at crossing points and along repeat tracks. This is considered to be an indirect approach to verifying EM-bias since it assumes that the transfer function between EM-bias and wind and waves is well understood (i.e., it accepts on faith that once $H_{1/3}$ is verified, EM-bias is verified). A great deal of research has been conducted to assure that the transfer function for TOPEX/POSEIDON will be adequate (Walsh et al., 1991).

A verification technique using altimeter transponders is being developed to verify EM-bias directly (see Section V.0.). A direct comparison between the spacecraft altitude relative to the sea surface and that relative to a transponder can be made. The extent to which they disagree can be directly attributed to EM-bias, since all other system biases are common to both observations. A minimum of two transponders will be used for TOPEX/POSEIDON verification. Site selection is currently under way.

2. Skewness Bias

Note that the word "bias" in the term "skewness bias," just as in the term "EM-bias," does not refer to a fixed error. The altimeter community has come to use the term to mean a systematic error that varies with the distribution of wave height and shape. Currently, no comprehensive scheme has been proposed to independently evaluate bias due to skewness during the verification phase of the mission. The skewness of the sea-surface probability density function (pdf) and how it relates to the pdf as seen by the radar is under continuing research (Rodriguez and Chapman, 1989). Skewness is thought to introduce an altimeter bias on the order of a centimeter or two for typical ocean scenes. Since there will be no objective analysis of skewness bias during the verification phase, we will have to treat it as a systematic error that may obfuscate our results to some degree.

3. Tropospheric Delay

Direct comparisons between the wet tropospheric delay derived from the TOPEX/POSEIDON Microwave Radiometer (TMR) and a minimum of two ground-based WVRs will be made. During the early part of the verification phase, the WVRs will be used to calibrate the TMR algorithms. Over the course of the mission, two identical WVRs will be deployed at the Platform Harvest and at Lampedusa. Uncertainties in troposphere delay will also be evaluated by comparing TMR data with the European Center for Medium Range Weather Forecast (ECMWF) model to monitor TMR bias and bias drift.

Because the TMR data taken at Point Conception may not be reliable due to the proximity of the oil platform to land, a WVR will be placed at the site to obtain the tropospheric delay correction for the altimeter. The alternative is to extrapolate the TMR data gathered on approach; however, there is concern that sharp discontinuities in water vapor near the coast may result in significant errors in extrapolation. If this does not prove to be a serious problem, the WVR may be moved to another site at the end of the intense verification period.

4. Ionospheric Delay

During the TOPEX/POSEIDON era, observations of ionospheric delay will be made by

- (1) GPS transmission to ground-based dual-frequency receivers.
- (2) GPS transmission to the TOPEX/POSEIDON dual-frequency receiver.
- (3) TOPEX/POSEIDON transmission to ground-based dual-frequency DORIS receivers.
- (4) Global models based on extant and historical data.
- (5) TOPEX/POSEIDON ALT data.

Nearly direct comparisons between the ionospheric delay inferred from the NASA altimeter, GPS receivers, and DORIS receivers will be made at a number of discrete sites around the globe. By "nearly direct" we mean that the instruments involved generally will not be looking through the same ionosphere and possibly not even at the same time. Analysis of the data will thus rest on the application of spatial and temporal models. This is particularly true for GPS, where the receiver data gathered on the ground and at the satellite must be combined to estimate the delay between the satellite and the ground. It is expected that this approach will adequately serve to verify the ionospheric correction derived from the NASA altimeter relatively early in the mission.

A similar approach will be used for the CNES altimeter; however, it is the ionospheric correction derived from DORIS data that will be verified. To verify the model, control and test groups of dual-frequency altimeter, GPS, and DORIS data will be used. With this, a reasonable assessment of the DORIS-based ionospheric correction can be expected well before the verification phase of the mission is over.

The most thorough and effective verification of the ionosphere model will result from the intercomparison of the model with dual-frequency altimeter data. Therefore, there is value in having an abundance of dual-frequency altimeter data for tuning and verifying the ionospheric delay model. As suggested by Figure II-1, the error spectra associated with the model will increase in power as the spatial scale decreases below a few hundred kilometers. This is expected since a mathematical model for the ionosphere will have difficulty predicting small-scale variability. A more precise description of this error spectra will follow from intercomparison with dual-frequency altimeter data during the verification phase of the mission.

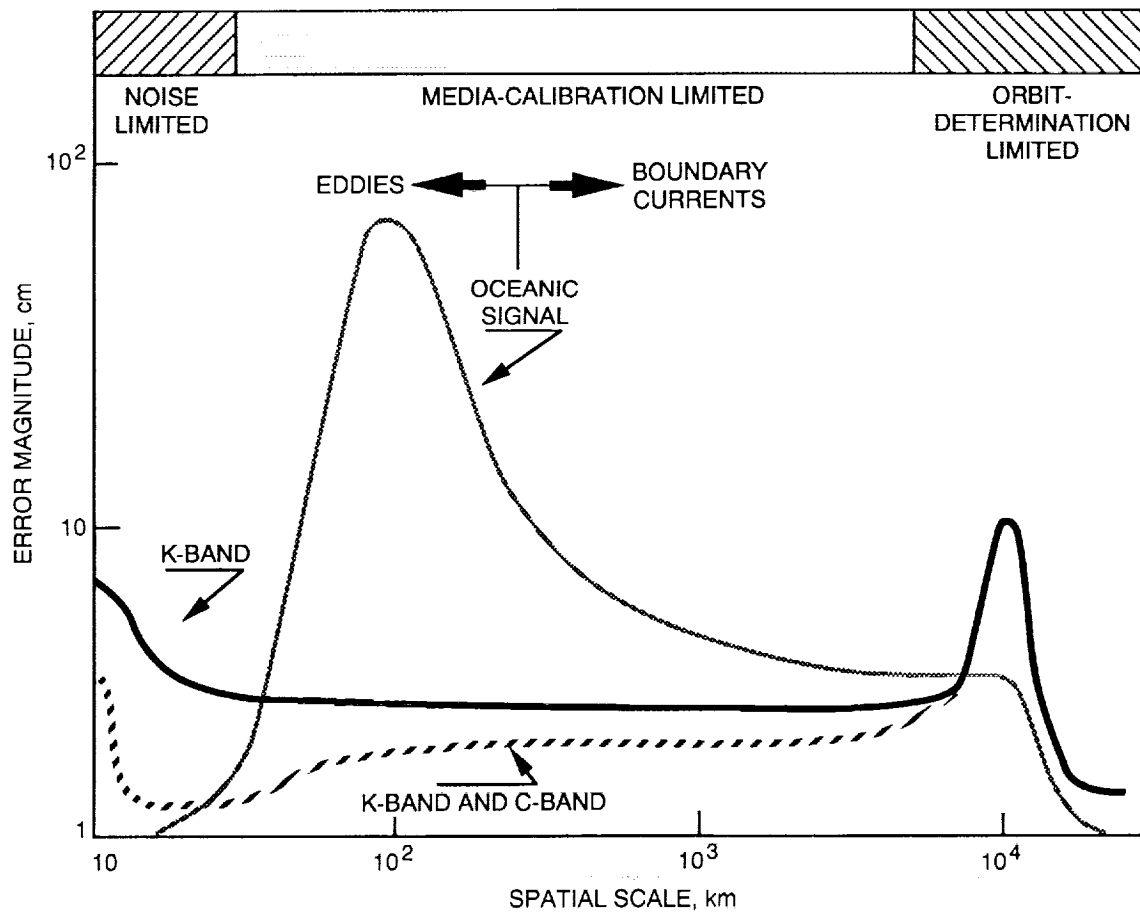


Figure II-1. Expected sea-level errors derived from TOPEX/POSEIDON altimetry as a function of spatial scale.

III. NASA Verification Activities

NASA is undertaking a wide range of verification and calibration activities to evaluate the performance of the NASA and CNES altimeters and the TOPEX Microwave Radiometer (TMR). These verification and calibration tasks will use in situ data for comparison with the spacecraft observations. Most of the in situ data to be used in the verification effort will be obtained through project-sponsored field campaigns, such as those planned at the NASA verification site and for the TMR calibration. Other routinely collected data, such as National Data Buoy Center (NDBC) buoy data, will also be utilized.

A. On-Site Verification at the Primary NASA Verification Site

Many of the activities performed in support of NASA verification will occur at a single location, known as the NASA verification site. The purpose of this site is to collect, in a single location, the in situ data necessary to independently verify the performance of the TOPEX/POSEIDON altimeters. From this on-site verification, an estimate will be made of each altimeter's bias, that is, the difference between the expected altimeter-to-ocean distance and the actual distance measured by the altimeter. Bias is of interest when data from more than one altimeter are combined to evaluate long-term trends in the ocean and to measure our understanding of the operation of the altimeter and the processing of data. Of greater importance is the bias drift. Ideally, the altimeter should have no bias drift. The measurement system should be stable. However, if the instrument bias drifts over time, the impact on the scientific results could be significant.

The concept of on-site verification is illustrated in Figure III-1. As the satellite overflies the verification site, it is tracked by lasers. The position of the satellite over the verification site is determined using short-arc orbit analysis (see Subsection III.D.) to within a few centimeters in the vertical. The location of the verification site relative to the lasers is established using Global Position System (GPS) receivers. Finally, the necessary measurements are made from the GPS receiver to sea level. An estimate of the satellite-sea-level distance is obtained using triangulation and is compared to the altimeter measurement. This concept has recently been successfully employed to calibrate the ERS-1 altimeter (Scharroo et al., 1991).

There are several factors to be considered when selecting a verification site. A primary requirement is that it be located far enough from land to avoid contamination of the altimeter signal. In addition, the site itself must be small enough to not affect the altimeter's response. The

logical choices for a verification site are limited to a small island or an oil platform. An evaluation of several potential locations for the NASA verification site—including Bermuda, oil platforms in the Gulf of Mexico, and oil platforms off California—was made. There were several considerations in the selection process:

- (1) Available laser coverage.
- (2) Anticipated accuracy of the in situ observations.
- (3) Logistics.
- (4) Costs.

The decision was made to instrument an oil platform located off Point Conception, California. Several oil platforms were considered. Texaco's Platform Harvest, located 19.5 km west of Point Conception, California, was finally chosen as the NASA verification site (see Figure III-2). The selection was based on the excellent laser coverage (see Figure III-3) and logistical considerations. In March 1991, a Memorandum of Understanding was signed between Texaco USA, Inc., and JPL permitting the installation of instruments at the platform.

The instruments to be installed at Platform Harvest are summarized in Table III-1; their relative locations on the platform are illustrated in Figure III-4. Three different types of sea-level-measurement systems will monitor the level of the ocean. The National Oceanic and Atmospheric Administration (NOAA)/National Ocean Service (NOS) will supply a Next Generation Water Leveling Measuring System (NGWLMS), which includes two water-level sensors: a self-calibrating acoustic device with an echo timing receiver and a backup pressure transducer/nitrogen bubbler combination. The University of Colorado (CU) is providing the third system—three pressure transducers. Two of the pressure transducers will be mounted below the water and the third will measure atmospheric pressure. The two submerged pressure transducers will be intercompared. The third pressure transducer will correct for the effects of varying atmospheric pressure. Ancillary ocean measurements, to be made by NOAA/NOS, include water temperature and conductivity.

The platform's location relative to the laser sites will be obtained by operating a GPS receiver at the platform. An experiment conducted at the platform by JPL has demonstrated that GPS data, averaged over a 3-day period, provide an estimate of the platform's position (in the horizontal and vertical) to better than 3 cm. Longer

averaging will further reduce the uncertainty. In addition to using GPS to obtain positional information, the GPS receiver will also provide an estimate of the total electron content (TEC) through a vertical column above the platform. The derived TEC value will be one of the checks made on the ionospheric correction, which is applied to the altimeter measurement (see Subsection III.C.3.).

Although the location of Platform Harvest in relation to land will not affect the altimeter signal, it is anticipated that because of the TMR's significantly larger footprint, land will contaminate the passive microwave TMR observations as TOPEX/POSEIDON overflies the platform. The primary purpose of the TMR is to provide a columnar atmospheric water-vapor estimate so that the altimeter observations can be corrected for the effects of water vapor. At the platform, this correction will be derived using an upward-looking water-vapor radiometer (WVR). A JPL J-Series WVR will be mounted near the platform's heliport to perform this task. Ancillary atmospheric measurements of relative humidity and temperature will be made by NOAA/NOS.

The computers associated with the verification instrumentation at the platform will be housed in a small custom-made equipment shed. In addition to collecting and storing data, equipment in the shed will provide clean power and communications via satellite (NOAA/NOS data only) and cellular telephone.

The final measurement required to tie the GPS estimate of location—made near the top of the platform—to the sea-level observations is a vertical measurement between the two locations. This vertical distance of about 45 m is difficult to obtain because the measurement must be made down narrow stairways, which are exposed to the wind, and the platform itself is swaying. Despite these problems, NOAA/NOS personnel surveyed this vertical distance with an estimated accuracy of 4 mm. Additional surveys will be conducted about once per year during the mission.

The motion of the platform has been a significant concern since Platform Harvest was selected as the NASA verification site. Sitting in 670 ft of water, the platform (including the derrick) is taller than the Eiffel Tower. Wind and wave action can produce a noticeable sway. The critical issue for verification is the effect of the sway on the vertical location of the verification instruments. The University of Colorado has conducted an experiment at Platform Harvest using an accelerometer designed to measure vertical acceleration and, thus, motion. This experiment occurred during high wind (70+ mph) and wave (up to 35 ft) conditions. The resulting vertical motion was less than 1 cm. During less severe conditions, the motion was found to be considerably less. Under "normal" conditions, the

motion of the platform is not expected to significantly affect the point verification results.

Table III-2 presents the error budget for the verification site. The errors specified are for a single overflight. Additional overflights will reduce the variable errors, but not the fixed errors. The largest variable error is expected to come from the spatial variability of the ocean within the altimeter footprint. This error results from comparing a point in situ measurement with the altimeter observation averaged over a several-kilometer footprint. After consideration of the potential error sources related to the in situ measurements at the verification site, the expected accuracy of the in situ measurements is better than 3.5 cm. When the estimated errors in the altimeter measurement and altimeter orbit (Table III-3) are included, the projected error in comparing the altimeter-derived height with the in-situ-derived height is 5.2 cm for a single overflight. This error decreases as the number of overflights increases (see Table III-4).

B. Calibration of the TOPEX Radar Altimeter

Goddard Space Flight Center (GSFC)/Wallops Flight Facility (WFF) verification support of the TOPEX altimeter geophysical measurements and science data products began before launch and will continue throughout the mission. WFF support for the TOPEX altimeter verification effort has multiple facets:

- (1) The TOPEX Altimeter Sensor Development Manager and engineering support team reside at Wallops and provide ongoing engineering performance assessments.
- (2) As members of the TOPEX Satellite Performance and Analysis Team, WFF provides the altimeter command files, calibration-mode data processing, and instrument health reports.
- (3) As members of the TOPEX Measurement System Team, WFF analyzes altimeter data products.
- (4) WFF has developed and tested 24 of the altimeter data algorithms and continues to verify them using prelaunch and eventually postlaunch altimeter data.
- (5) WFF has developed and tested altimeter data processing and analysis software to monitor instrument performance. The capability to electronically transmit data to and from JPL has been demonstrated; file exchanges are now routine.

- (6) Throughout the phases of prelaunch altimeter testing, WFF has established a performance data base. Using this data base, comparisons may be made to confirm predevelopment specifications and postlaunch performance.

Table III-5 provides a general summary of WFF on-orbit verification activities.

1. On-Orbit Verification Activities

The initial 35 days after launch, the Engineering Assessment Phase, is dedicated to establishing that the satellite, sensors, communication links, and ground equipment function properly together. During this phase, data collection for the geophysical parameter validation begins.

During the Engineering Assessment Phase, WFF will verify that the altimeter responds appropriately to commands and operates in its tracking and calibration modes. An ongoing assessment will determine the degree to which altimeter engineering measurements are stable and within design limits. Measurements from science frames (range, range-rate, automatic gain control (AGC), $H_{1/3}$, waveforms, and internal calibrations) will be evaluated in terms of precision and internal consistency. In the event of abnormalities, WFF will recommend and document any necessary corrective actions.

During the Intensive Verification Phase in the 6-month period immediately following launch, the satellite sensor data will be sent by JPL to WFF in the form of selected telemetry records, Sensor Data Records (SDRs), and Interim Geophysical Data Records (IGDRs). Figure III-5 summarizes the primary data interfaces between the WFF verification effort and the TOPEX ground system (TGS). The altimeter parameters to be verified during this initial 6-month period are listed in Table III-6.

Approximately $4\frac{1}{2}$ months after sensor turn-on, WFF will participate in the verification workshop to be held at JPL. At that time, WFF analyses will be presented, and results will be compared and then integrated into a workshop report.

2. Data Quality Monitoring Activities

After the Intensive Verification Phase is complete, monitoring of GDRs will be performed to ensure the continued data quality of the geophysical parameters. WFF will process altimeter calibration-mode data and monitor key performance requirements. Any changes or long-term trends will be examined carefully to determine whether the results indicate local geophysical changes or whether instrument or processing errors are evident.

During the past 18 months, WFF has developed an extensive system for quick analysis of TOPEX altimeter data from the altimeter development and testing stages; this analysis system has been expanded to process the TOPEX data as it is received from JPL. The WFF in-house experience with the sensor development and testing dataset will be particularly valuable during the on-orbit verification effort.

C. Calibration of the TOPEX Microwave Radiometer

One of the important corrections that must be applied to the altimeter observations is that for atmospheric water vapor. The instrumentation on the TOPEX/POSEIDON satellite includes a nadir-pointing microwave radiometer, the TMR, to estimate atmospheric water vapor. To obtain the precision required in the water-vapor correction, the TMR's water-vapor retrievals must be finely calibrated. This will be accomplished by deploying two upward-looking WVRs along the TOPEX/POSEIDON ground track to monitor water vapor as the satellite flies over. These in situ observations will be used to calibrate the TMR.

The WVRs to be deployed will include one of the two J-Series built by JPL for the TOPEX/POSEIDON Project and a custom-built WVR supplied by the University of Massachusetts (UMass). The J-Series WVR will be installed at the CNES verification site at Lampedusa in the Mediterranean during the 6-month postlaunch verification period. The UMass WVR will be located at two islands in the Pacific, at each for several weeks. The Pacific campaign will include a dry location—Norfolk Island, Australia—and a humid location—Chichi Jima Island, Japan. By sampling both dry and humid locations during TOPEX/POSEIDON overflights, the TMR can be calibrated over its full range.

In addition to the planned calibration campaigns in the Mediterranean and the Pacific, it is hoped that the J-Series WVR at the NASA verification site will also be useful in both the TMR calibration and long-term monitoring of the TMR's performance. Whether or not this WVR will be suitable for these tasks will depend on how much land contamination there is in the TMR signal at the platform and how accurately the TMR data can be analyzed.

Plans are being developed to maintain the J-Series WVR at Lampedusa for the duration of the mission. This WVR will provide a long-term calibration of the TMR.

D. Data Analyses

A number of analyses are planned as part of the NASA Calibration-Validation (CAL/VAL) Program. These range from the determination of the bias, called the "closure analysis," to evaluating altimeter-derived wind and wave

parameters. Closure analysis involves short-arc orbit determination and sea-level measurements derived from altimetry.

1. SLR Short-Arc Orbit Determination

Satellite Laser Ranging (SLR) measurements will be used to determine the satellite height above the reference ellipsoid. Two types of SLR measurements will be obtained from the Crustal Dynamics Project Data Information Center (CDDIS). These are called "quick-look" and "full-rate." The quick-look data will be available 3 working days after acquisition, while the full-rate data will not be available until 60 days after the acquisition month. For laser stations tracking near the verification site overflights, the Crustal Dynamics Project Satellite Laser Ranging (CDSLR) network has agreed to provide full-rate data within 5 working days after acquisition. The SLR data will be collected by the Precision Orbit Determination and Verification Team (PVT) and stored on an HP720 computer. They will then be converted to an internal format for use in the JPL orbit-determination program MIRAGE. An a priori trajectory based on the operational orbit ephemeris (OOE) and precision orbit determination (POD) models will be used to obtain a best-fit solution to the observed SLR data near each verification site. The new orbit, referred to as the short-arc orbit (SAO), will then be passed to the TGS VAX computer system for closure analysis.

2. GPS Short-Arc Orbit Determination

An alternative method for determining satellite height above the reference ellipsoid relies on GPS technology. The experimental GPSDR carried on the spacecraft will collect GPS pseudorange and carrier phase at L1 and L2 frequencies from up to six GPS satellites simultaneously. Comparable information collected by six globally distributed ground receivers will then be combined with the flight data to estimate clock offsets of transmitters and receivers, orbits for GPS and TOPEX/POSEIDON, locations of ground receivers, and other parameters such as tropospheric path delays and phase biases. The anticipated performance of this GPS-based tracking system is subdecimeter altitude accuracy for TOPEX/POSEIDON (e.g., Wu et al., 1991).

Owing to the geometric diversity and continuity of the GPS measurements, the spacecraft orbit can be determined without the aid of precision dynamic models of the forces acting to perturb its motion. Studies suggest, however, that it is helpful to retain some dynamic information in the solution strategy to accommodate periods of weakened viewing geometry. This "reduced dynamic" approach (Wu et al., 1991) will be adopted for computing the TOPEX/POSEIDON orbits from the GPS data.

Covariance analyses indicate that because the dynamic models can be deweighted, corresponding to increased reliance on the more data-intensive geometrical solution, no special benefit is derived from computing short-arc orbits. In fact, longer arcs permit the highest orbit accuracies because the effects of measurement noise average down. Analysis has also shown that the results are fairly insensitive to the relative weights assigned to the dynamic models and to the GPS data. Thus, one's assessment of the accuracy of the existing dynamic models for the spacecraft need only be approximately correct.

The experimental TOPEX/POSEIDON GPS orbits will be computed at JPL using the GPS POD software. Arc lengths of 2 to 8 hours will be considered, with the expectation that the altitude error will decrease monotonically with data span until a limiting value of a few centimeters (governed by fiducial errors) is reached. The height of the TOPEX/POSEIDON orbit with respect to the reference ellipsoid as it passes over the Harvest verification site will be supplied directly to the TGS VAX computer for closure analysis.

The nominal approach for computing these orbits will use data from the GPS receiver on the platform in addition to the six primary global tracking sites. Because the platform data will also be included in the solution, the baseline distance between the satellite and the platform will be a by-product of the analysis. Local survey data can be used to refer the height to sea level, a value which can be compared with the result from the closure software as a means of corroboration. The GPS results will in turn be compared with those derived from the laser SAO.

Note that JPL is planning to work directly with colleagues at CNES to combine GPS and DORIS data for TOPEX/POSEIDON orbit determination. JPL software will have the capability to process DORIS data separately or simultaneously with the GPS measurements. (SPOT-2 orbit solutions based on DORIS Doppler measurements have already been produced.) This software may eventually be capable of incorporating laser tracking as well. Such additional data types could be included (or used for alternate solutions) on a best-effort basis.

3. Closure Analysis

In situ measurements collected from the NASA verification site will be used with the SAO to obtain estimates of the altimetric system bias and bias drift. Figure III-6 delineates each of the constituents of sea level as measured by the altimetric and in situ systems. For perfect closure, the bias will be zero or at least constant in time. Systematic errors in any one of the constituents will be

observed in the bias; therefore, it is important that such errors are either minimized or calibrated independently.

In Figure III-6, H_{SAT} is the height of the satellite relative to the reference ellipsoid obtained from the SAO. H_{GPS} is the related height of an in situ reference mark at the verification site and is obtained by performing a GPS baseline solution relative to one or more of the fiducial laser tracking stations. H_{GP} and H_{PT} will be determined from a local survey and tie together the GPS and tide-gauge reference marks. H_{TG} is the tide gauge measurement at the time of satellite closest approach. H_{GG} is the cross-track geoid gradient correction; this correction can be derived from the overflight miss distance and geoid data. R_{GDR} represents the measured range from the satellite to the sea surface corrected for instrumental and path delays.

For TOPEX/POSEIDON, R_{GDR} is reported on the Geophysical Data Record (GDR) along with the delay corrections. $R_{MEASURED}$ is the smoothed and uncorrected altimeter range measurement. R_{INST} is the instrument range correction; it represents delays due to oscillator drift, center of gravity shift, and acceleration and doppler shift corrections. The electromagnetic (EM) bias correction, R_{EMBIAS} , is necessary because ocean wave troughs are better reflectors of microwave energy than the wave crests. Estimates of the EM bias can be determined from $H_{1/3}$ and wind-speed measurements obtained at the site of interest. R_{IONO} is the ionospheric delay; if the altimeter makes dual-frequency measurements, this correction can be determined directly. In addition, the total zenith electron content, on which the ionospheric delay is dependent, can be obtained from GPS measurements. R_{WET} and R_{DRY} are the wet and dry tropospheric delays; for the NASA verification site, in situ meteorological and WVR measurements will be used to determine these delays.

4. Ionosphere Correction Analysis

As discussed in Subsection II.B.4., one of the important corrections to the altimeter data is ionospheric delay. The ionosphere correction derived from the dual-frequency NASA altimeter will be evaluated by comparing it to independently obtained estimates of the ionosphere. The methodology used to obtain independent path-delay estimates includes

- (1) Path delays derived from GPS data.
- (2) Path delays derived from DORIS data.
- (3) Global models.

Both the GPS- and DORIS-derived delays will be available along much of the TOPEX/POSEIDON orbit. However, these estimates of the ionospheric delay are based

on line-of-sight observations that typically are significantly different than the nadir-looking altimeter. Comparable nadir-looking ionospheric delays are estimated using the line-of-sight data. The accuracy of this type of methodology depends on the temporal and spatial distribution of satellites (for GPS) or receiving stations (for DORIS). The global models are expected to be much less accurate than the other techniques because these are typically based on average solar activity and are not designed to provide a synoptic view of the ionosphere.

5. Wind Speed and Wave Analyses

Altimeter observations can be used to estimate both $H_{1/3}$ and wind speed. $H_{1/3}$ is directly obtained during altimeter-data processing. In contrast, wind speed must be derived using a "model function" from the σ_0 value returned by the altimeter. Both quantities provide a useful check on the performance of the altimeter because they can be readily compared with available buoy data.

National Data Buoy Center data will be obtained in near-real time from a commercial service, The Weather Network, Inc., which provides on-line access to the data via modem. Buoy data within 50 km of the ground track and 12 hours of a TOPEX/POSEIDON overflight will be collected and analyzed. Of particular interest is the Point Conception buoy located about 19 km south of the NASA verification site (see Figure III-2) and less than 4 km from the TOPEX/POSEIDON ground track. In addition to the buoy data, $H_{1/3}$ data will be derived from the CU pressure transducers mounted at the NASA verification site (see Subsection III.A.).

E. GSFC Verification Activities

The primary GSFC verification activities will be the use of Lampedusa laser tracking and TOPEX altimeter overflights of Lampione to estimate the TOPEX altimeter bias for ionospheric corrected data. The procedures for accomplishing this bias estimation, plus other related activities, are outlined below.

1. Orbit Estimation

a. Lampedusa. Short-arc orbits will be estimated using the GEODYN II program and laser data taken by the Lampedusa laser. This laser data will provide the satellite height and along-track coordinates as the satellite overflies Lampione. Additional data are needed to provide the satellite out-of-plane coordinates. This will be done using other European laser data when they are available. When they are not available, the information will be provided by global lasers, either in the form of lightly weighted observations or in the form of constraints provided from a preliminary operational orbit obtained using global laser tracking.

b. Platform Harvest. Short-arc orbits will be estimated when two or more lasers in the western United States track a TOPEX/POSEIDON overflight of Platform Harvest. The orbit estimation procedure does not differ significantly from that used for Lampedusa. After analysis to verify that there are no data problems, all orbits will be provided to JPL, where they will be available to all verification participants.

2. Lampedusa/Lampione Calibration

a. The creation of independent altimeter measurements. This will be the first step in TOPEX altimeter data processing and is a unique activity at GSFC. The height data telemetered from the TOPEX altimeter will be the output of an α - β filter, so they have time-correlated errors over a period of about a second for normal low-sea-state tracking. Errors are thus smoothed at about twenty telemetered measurements. This makes it difficult to identify any unusual returns that might have small effects on measurements in the vicinity of the calibration site. However, because the parameters of the α - β filter are known and both height and height rate are recorded and telemetered, measurements with time-independent errors can be recreated on the ground. Since the full 20/sec data rate is required and the IGDR files contain only 10/sec data, the Sensor Data Record (SDR) files must be used. In addition to the improved ability to identify anomalies around the calibration site, less data will be lost if data editing is required. Data with independent noise is also more compatible with the smoother, which is planned for use to reduce the effects of noise and obtain the best height estimate at the actual calibration point (the point at which the ground track passes closest to the tide gauge on Lampione).

b. Height calibration using GEODYN II. There is an advantage in using the altimeter data in the orbit estimation program (along with the laser tracking data used for orbit estimation) to compute the height above the ellipsoid (sea-surface height) that the altimeter data predict when no bias is applied. The advantage is that certain effects are automatically incorporated, particularly the effects of earth tides and ocean loading. Accordingly, this process will be followed with the 20/sec data computed as described above. To estimate height bias, propagation corrections based on ground measurements (pressure, temperature, and microwave radiometer measurements) will be made and the altimeter-deduced sea-surface height made will be compared with the tide-gauge measurement of sea-surface height. For the TOPEX altimeter, this will be calculated independently for Ku-band and for C-band if ionospheric correction measurements are available (from DORIS or from GPS) in addition to being calculated for the ionosphere-free measurements based on TOPEX altimeter data alone.

c. Altimeter data smoothing using ALTKAL. The altimeter estimate of sea-surface height is needed for height bias calibration at only one point, namely at the closest point to the tide gauge. The measurements computed using the 20/sec SDR data will have a noise level of about 15 cm. By comparison, the telemetered measurements will have a noise level on the order of 3 to 4 cm but will have already been smoothed over approximately the previous second. Since geoid features in the vicinity of the calibration site are relatively small and of long wavelength, data smoothing can improve the accuracy level. For this application, GSFC will use the ALTKAL (ALTimeter KALman) smoother developed for smoothing GEOS-3 data and used for extrapolating across Bermuda for Seasat altimeter calibration. In particular, GEODYN II altimeter residuals will be smoothed using geoid undulation and amplitude parameters appropriate for the Lampione area. Should data editing be required, the program allows either automatic editing or the culling of bad data points. In addition to smoothing the three types of data discussed above (Ku-band, C-band, and combined), experiments will also be made in smoothing the ionospheric correction calculated from the Ku- and C-band data. The advantage of this approach is that the Ku-band data have the lowest noise level, so the error in the smoother output due to noise will be less than that in the combined data, while the ionospheric correction can be smoothed over a much longer wavelength than can the altimeter heights.

d. Auxiliary activities. Various other activities will also be necessary to support Lampedusa-Lampione calibration. The geoid slope around Lampione is somewhat known from Geosat tracking, but whether it is of sufficient accuracy for TOPEX calibration has yet to be assessed. Further analysis will be necessary. The GPS tie between the Lampedusa laser and the Lampione tide gauge has not yet been made and its accuracy must be assessed. If the GPS data can be obtained, an independent estimate of the relative heights will be made. The offset of the TOPEX altimeter feedhorn (or other reference point) from the spacecraft center of mass must be reliably calculated and continuously updated. Confidence will also have to be gained that the corrections applied for the laser tracking point offset from the spacecraft center of mass are consistent and without significant error. It is also necessary to determine if spacecraft attitude changes require a height correction to altimeter measurements. The form in which tide-gauge data will be obtained is not yet known and may require smoothing. Processing and assessment of tide-gauge data prior to launch will be performed.

e. Calibration using ascending TOPEX passes south of Lampedusa. The TOPEX ground track pattern has an ascending pass that crosses the ground track of the Lampione overflight pass some 60 km southeast of Lampedusa. This

ascending pass is sufficiently close to Lampedusa that Lampedusa laser tracking can be used to provide a spacecraft height that is almost as accurate as that provided for the Lampione overflight. This pass can thus be used for calibration on all passes with Lampedusa laser tracking and for which the TOPEX altimeter is on. To use the ascending pass for calibration, a sea-surface tie must be obtained between some point on the pass and the Lampione tide gauge. There are two basic elements of this tie:

- (1) *Geoid height estimation on the ascending pass.* This can be done using the Lampione overflight passes, of both TOPEX and POSEIDON, to determine the relative sea-surface heights between the Lampione pass and the ascending pass. A tide-gauge model (Sanchez-Ray or a French model, if available) will be used to estimate the relative tide heights between the ascending pass and the Lampione overflight pass at their crossing point. The ALTKAL smoother will be used to minimize extrapolation errors. Extrapolation from multiple passes will also help to reduce this error.
- (2) *Sea-surface height estimation on a calibration pass.* With the TOPEX altimeter on and Lampedusa laser tracking for an ascending pass, the combination of the Lampione tide-gauge measurement and a Mediterranean tide model will be used to estimate the sea-surface height for an ascending pass calibration. Meteorological data

from Lampedusa will have to be used and a change in barotropic effects between Lampione and the calibration point will have to be considered negligible.

3. Platform Harvest Calibration Support

As indicated above, Platform Harvest will be supported via the estimation of short-arc orbits to be supplied to the TOPEX/POSEIDON Project. In addition, the altimeter data over the tower will also be processed as it was for the Lampedusa/Lampione calibration, using the 20/sec SDR files and the ALTKAL smoother. For California, the independent measurements will allow the use of data closer to the coastline than that used in smoothing the filter output. In addition, any effects of the platform on the altimeter return should be easier to identify and to edit.

4. Consistency Checks

Numerous activities will be performed to verify that subtle errors are not being made or that necessary corrections are not neglected. IGDR data will be processed, particularly slightly away from the calibration sites, to insure that the time tags used are consistent and that any differences are understood. For regions having constant geoid slopes, smoothing both IGDR and SDR data should give essentially identical results. With a nonzero slope, any differences in timing should be readily apparent. Comparing calibrations of the ascending Mediterranean passes with the Lampione overflights should be a check on the overall time-tag accuracy. Comparisons with CNES and others should also be a check, since each is likely to be doing something slightly different.

Table III-1. NASA verification site instruments.

Instrument	Parameter	Responsibility
Sea-level instrumentation	Sea level	
NGWLMS (acoustic)		NOAA/NOS
NGWLMS (N ₂ bubbler)		NOAA/NOS
Pressure transducers		CU
Rogue GPS receiver	Position and columnar total electron content	CU/JPL
Water-vapor radiometer	Columnar water vapor	JPL
Barometer	Atmospheric pressure	NOAA/NOS
Hygrometer	Relative humidity	NOAA/NOS
Thermometer	Atmospheric temperature	NOAA/NOS
Ancillary ocean instrumentation	Water temperature	NOAA/NOS
	Water conductivity	NOAA/NOS

Table III-2. Verification site error budget.

Source	RSS error, cm	
	Fixed	Variable
GPS survey		
Survey error	2.0	0.0
Platform sway	0.0	0.5
Thermal expansion of platform (below water line)	0.0	0.5
Other vertical changes	0.0 ^a	0.0
Platform survey		
Survey error	0.5	0.0
Thermal expansion of platform (above water line)	0.0	1.0
Sea-level measurement		
Instrument zero	0.0	0.0
Instrument noise	0.0	1.0
Geoid cross-track variability	0.0	0.5
Ocean spatial variability	0.0	2.0
RSS total	2.06	2.60
RSS total (fixed + variable)	3.32	

^a At the time of the GPS survey; this value may change (increase) between surveys.

Table III-3. Laser tracking and altimetry errors for a single overflight.

Source	RSS error, cm	
	Fixed	Variable
Instrument	—	2.0
Dry tropospheric correction	0.0	0.7
Wet tropospheric correction	0.5	0.5
Ionosphere correction	1.0	0.5
EM bias	1.4	1.4
Skewness	0.0	1.0
Total altimetry error	1.8 ^a	2.8
Orbit height error from laser tracking	2.0	1.0
RSS total	2.69	2.97

^aDoes not include altimeter bias.

Table III-4. Expected error as a function of number of overflights.

Number of overflights	Total rms error, cm ^a	Variable error contribution, cm ^a
1	5.2	3.9
3	4.9	3.6
5	4.6	3.1
10	4.1	2.3
20	3.8	1.7
30	3.7	1.4

^aIncludes contributions from the in situ measurements, laser tracking, and altimetry. The method includes estimation of bias and bias drift.

Table III-5. GSFC/WFF on-orbit verification.

Point of verification	Activity
Initial Phase	Receive selected SDRs and IGDRs Perform selective processing Receive selected telemetry data Process all calibration mode data Perform comparisons with preflight baselines Establish flight baselines
Mission Phase	Receive selected telemetry data Receive two SDRs per month Receive all GDRs Process all calibration mode data Perform selective processing Perform comparisons with initial phase baselines
Spacecraft Analysis Team Member	Perform trend analysis (e.g., temperature) Perform calibration mode analysis/trends Provide command support
Science Verification System	Determine selective global average trends Receive ground truth, as required

Table III-6. GSFC/WFF initial phase verification.

Parameter to be verified	Method
Range measurement	Targets of opportunity
Precision across $H_{1/3}$	Range corrections from waveform processing
Ionosphere	Collaboration with other investigators
EM-bias	Repeating groundtrack studies
$H_{1/3}$	Comparisons with buoy data
	Comparison to waveform processes
AGC	Comparisons of daily means
	Correlation with attitude
Calibration modes	Daily
Range	
$H_{1/3}$	
AGC	
Waveforms	Internal calibrations
	Waveform fitting modeling analysis
Range-rate measurement	Comparisons with ground processing
Attitude	Comparison of waveform-derived attitude with spacecraft-derived attitude
Time tag	Collaboration with other investigators

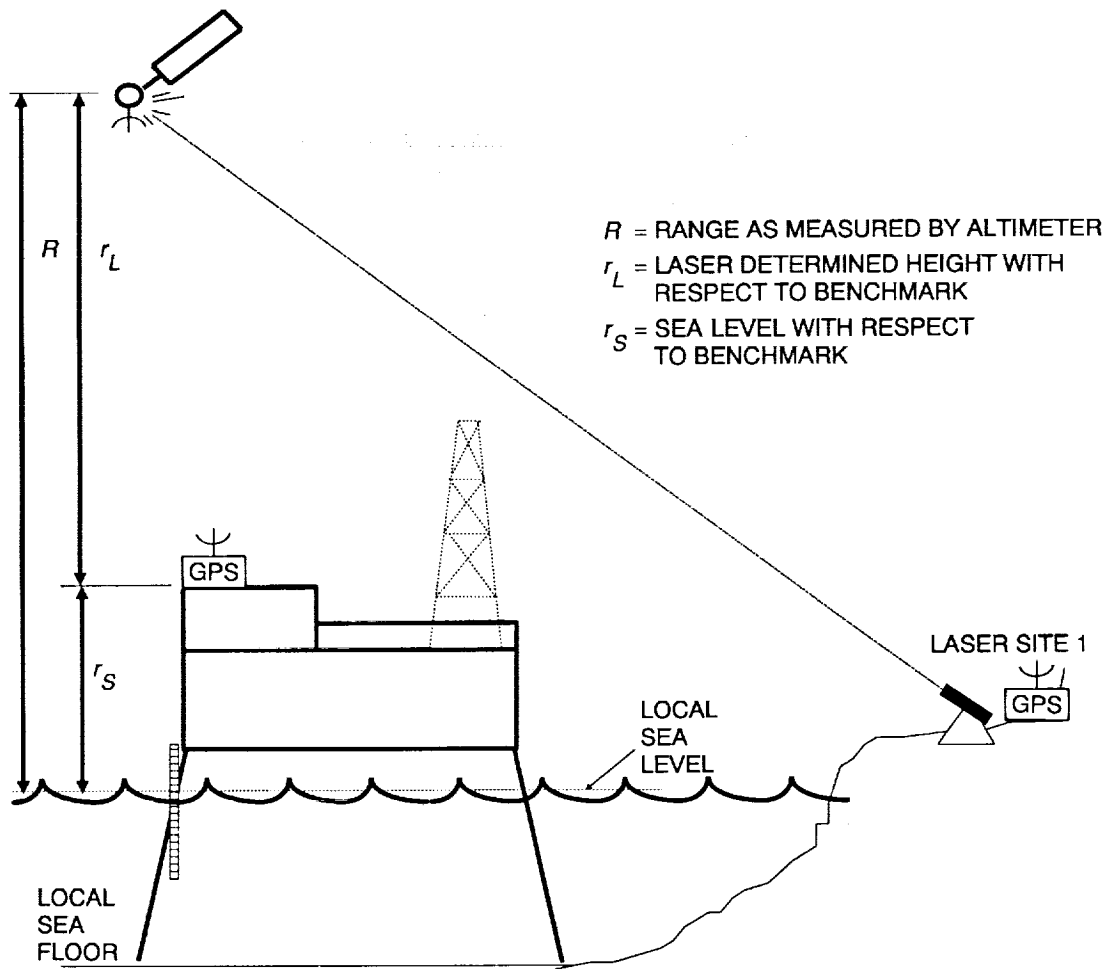


Figure III-1. On-site verification.

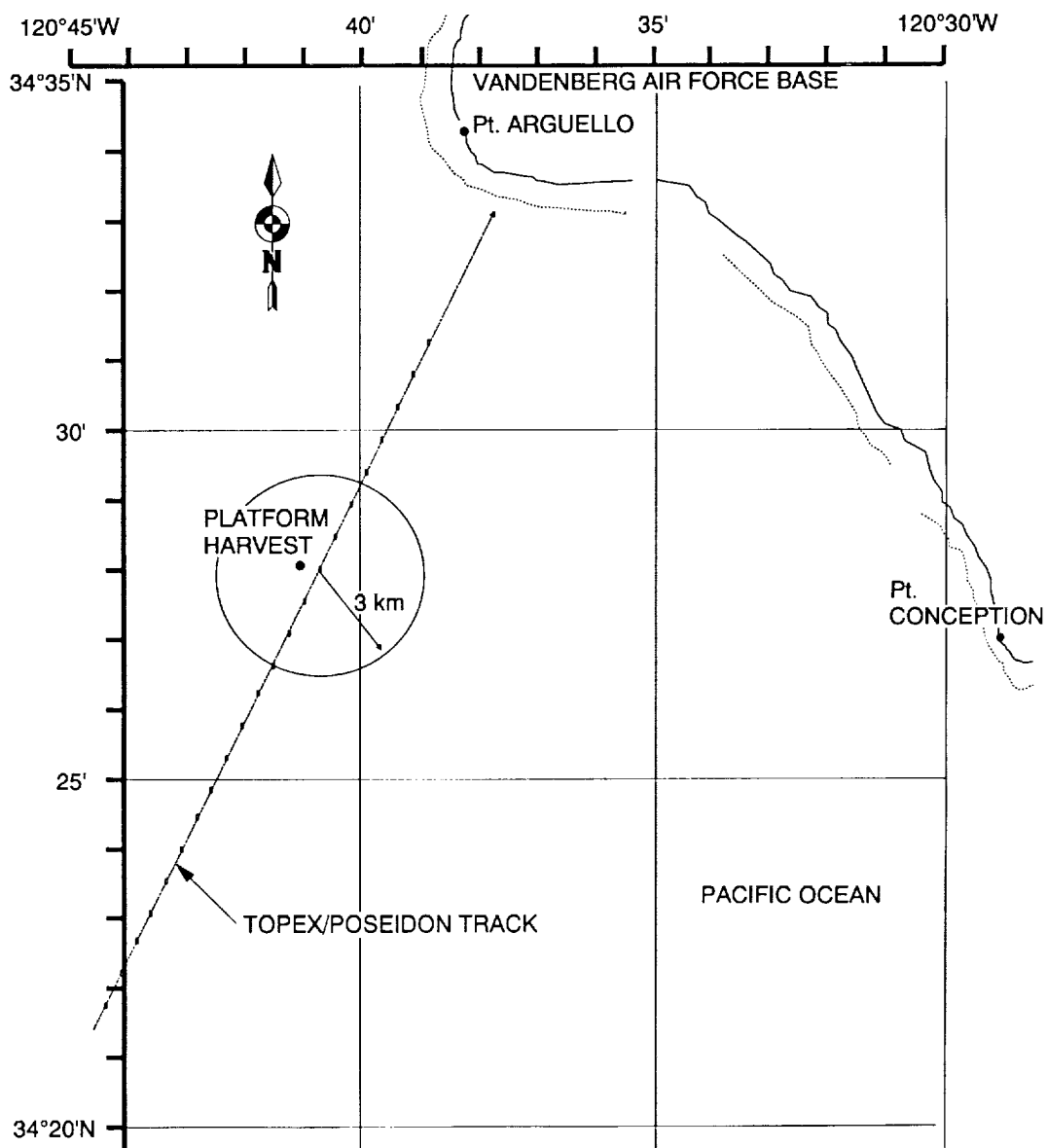


Figure III-2. The location of Platform Harvest.

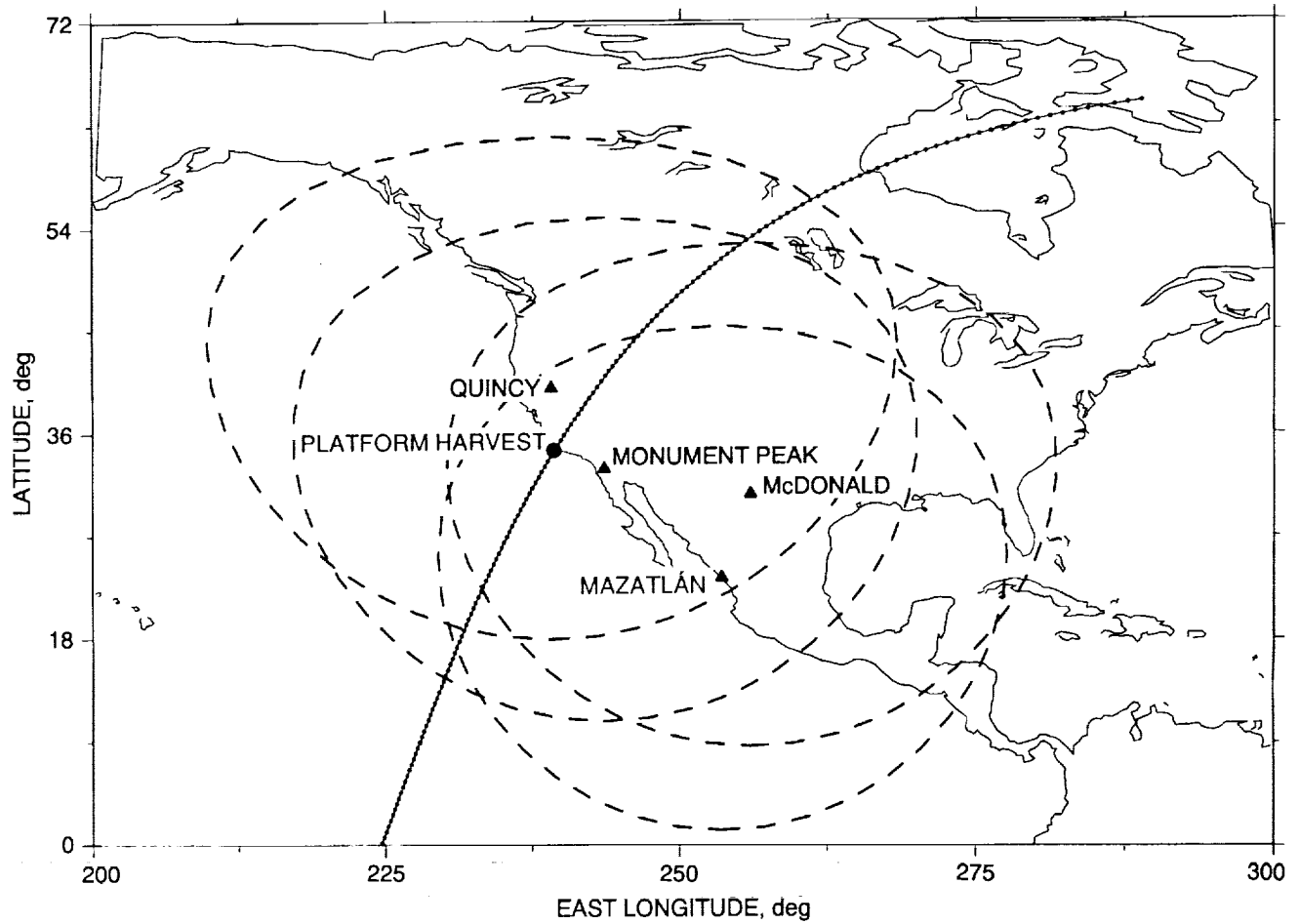


Figure III-3. Laser stations for Platform Harvest overflight.

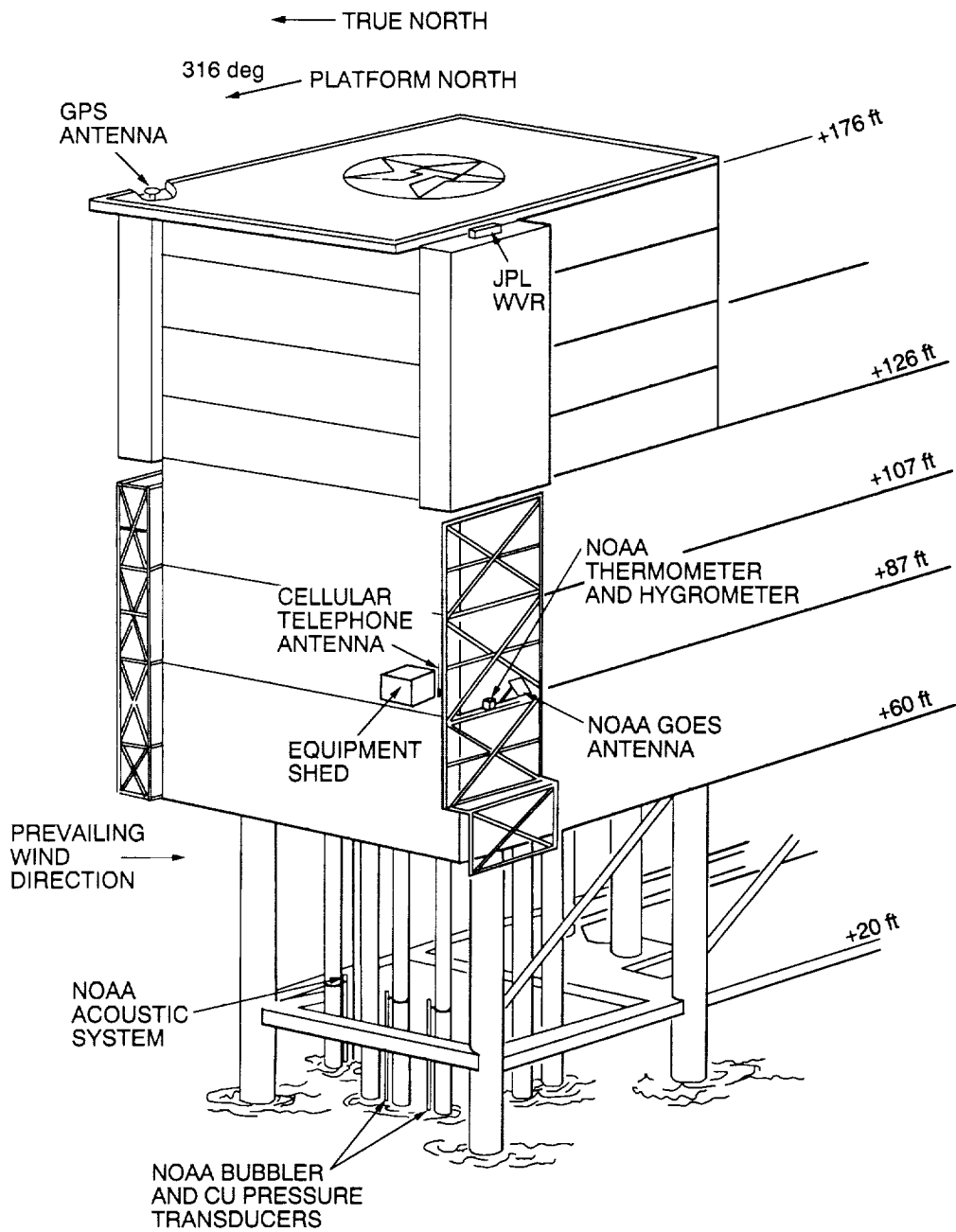


Figure III-4. Instrument locations on Platform Harvest.

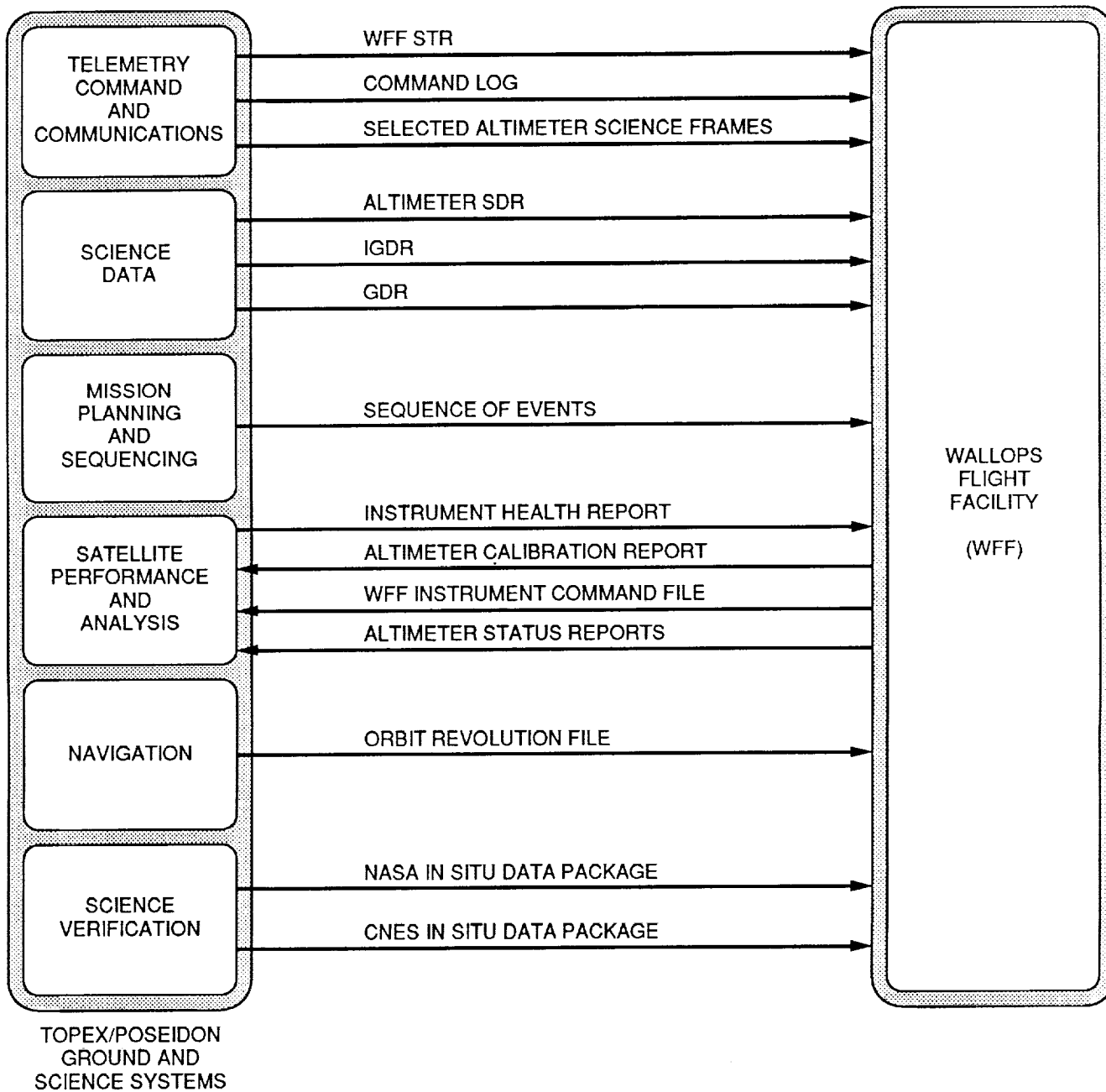


Figure III-5. Primary TGS-WFF data interfaces.

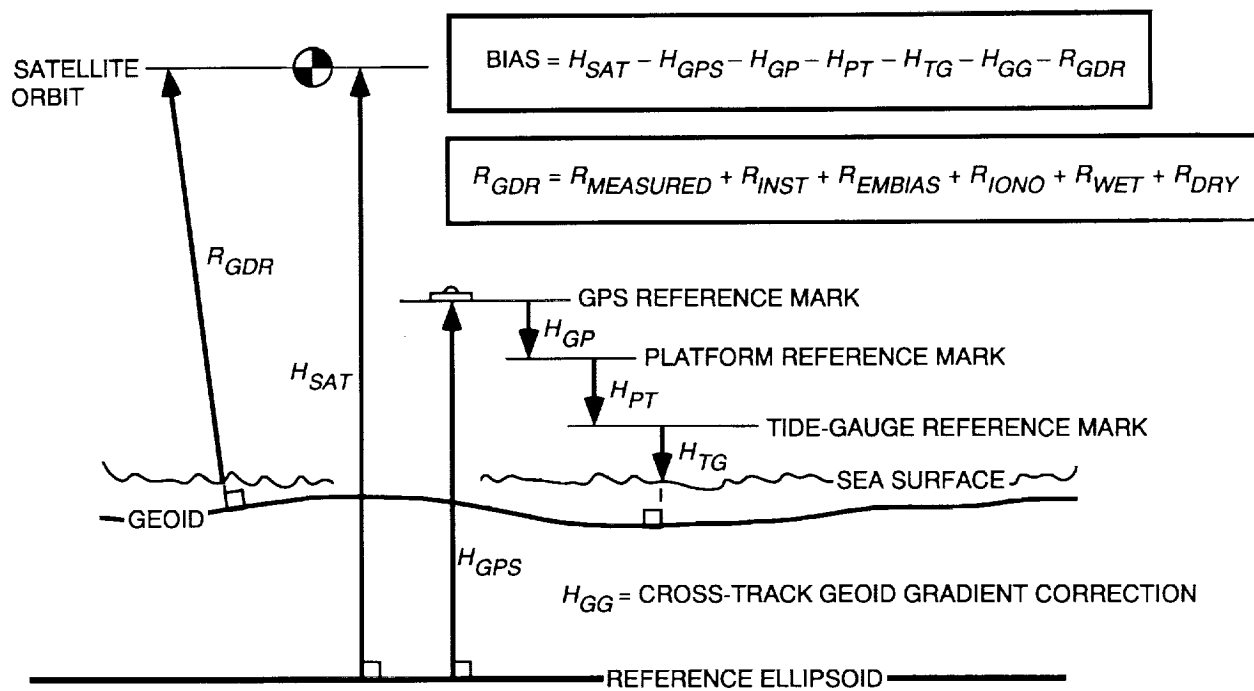


Figure III-6. Sea-level constituents as measured by the altimeter and in situ systems.

IV. CNES Verification Activities

The CNES TOPEX/POSEIDON verification plan and the CNES CAL/VAL (calibration-validation) Mission are defined in Menard and Vincent (1989) and Menard (1990). The technical organization is presented in Menard and Vincent (1991). CNES verification activities will be conducted by the CAL/VAL Team. This team will assess the altimeter products and associated geophysical algorithms. This assessment includes the POSEIDON onboard system verification, the calibration-validation of TOPEX/POSEIDON height and sea-level measurements and associated corrections (for ionosphere, troposphere, and EM bias), and the sea-state and wind-speed validation.

The CAL/VAL Team will be composed of two groups, one based at the Groupe de Recherches en Géodésie Spatiale (GRGS) and the other based at the Collecte Localisation Satellites ARGOS (CLS-ARGOS) company (near the Centre de Traitement DORIS/POSEIDON (CTDP) and the Analysis and Validation of Satellite Oceanographic Data (AVISO) centers). The CLS-ARGOS group will perform the ground processing, global statistics, and model cross-comparisons, while the GRGS group will perform the on-site (at Lampedusa and Platform Harvest) verification activities. In addition, external support from various expert groups is expected. The CNES CAL/VAL Mission group will conduct, with the support of CAL/VAL-CLS and CAL/VAL-GRGS groups, the synthesis of the CAL/VAL activities and will ensure interaction with the other CNES TOPEX/POSEIDON Mission groups, the NASA verification team, and involved expert groups.

A. On-Site Verification Activities

The verification activities at Lampedusa Island are detailed in the CNES Verification Plan (Menard and Vincent, 1989) and were the beginning of two contracts between CNES and Software Based Systems Company (SBS)—one to study the feasibility of the project and the environment of the site (Molines et al., 1989a) and the other to study the oceanic variability around the island and to propose an optimal instrumentation of the site (Molines et al., 1989b). Campaigns were defined and planned with the support of external groups; for examples, the Italian Consiglio Nazionale delle Ricerche-ENEA (CNR-ENEA) group from La Spezia participated in the oceanographic segment and Institut Für Angewandte Geodäsie (IFAG) directed the geodetic survey of the site. The purposes of such campaigns are to locally verify the consistency of the altimeter measurement, to calibrate the altimeter height (bias and drift), and to cross-calibrate the TOPEX and POSEIDON altimeters. The Lampedusa site will be equipped with all

the instruments (e.g., tide gages, meteorological station, and laser station) required to provide an external measure of the satellite range above sea level; this measure will be compared to the satellite-based measurement.

1. Location

Lampedusa, an Italian territory, is a small (7 km by 3 km), flat island in the Mediterranean Sea midway between Tunisia and Sicily (Figure IV-1). This site has several advantages regarding the TOPEX/POSEIDON altimeter verification issues. It is part of the Wegener-Medlas geodetic laser network and thus is periodically visited by a mobile laser station. Also, the Lampedusa area generally has little cloud cover, a relatively flat geoid with a regular gradient, a shallow sea bottom, low sea-level variability, and usually quiet sea-state conditions.

Moreover, 18 km west of Lampedusa there is an islet, Lampione (less than 300 m wide and 40 m high), that will be equipped with a tide gage tied by GPS to the laser station on Lampedusa and that will serve as the reference calibration point. The satellite orbit has been adjusted to overfly the Lampione tide gage. Thus the TOPEX/POSEIDON 10-day-cycle orbit will be phased to provide a descending pass overflying Lampione. The small extension of the islet should not affect the altimeter return signal as it was observed by Geosat.

2. Verification Site Measurement Concept

The easiest way toward verification is to directly combine the laser satellite tracking measurements acquired by the station on Lampedusa with the tide-gage sea-level measurements collected at Lampione. Thus, an independent measurement of satellite range above the tide gage is obtained and compared with the corrected altimeter range measurement. This operation requires a preliminary and very accurate GPS leveling between the tide gage and the laser station. This scheme has the advantage of integrating a limited number of data and thus minimizing the error sources. However, it is applicable only when the laser at Lampedusa and the tide gage at Lampione are both available and well functioning.

As a backup solution, the use of a model-based interpolation procedure is proposed. Such a method allows combination of the data provided not only by the laser and tide gage installed on the site, but also by surrounding instruments. The laser data collected at Lampedusa and other close laser sites (e.g., Grasse, Matera, Punta Sa Manta, Trapani, and Wetzell) can be combined with other tracking

data (e.g., DORIS data) through a short-arc technique to provide an accurate orbit of the satellite in the Lampedusa area.

The GRGS and Centre d'Etudes et de Recherches Géodynamiques et Astronomiques (CERGA) groups have developed such a technique based on dynamical methods (Biancale et al., 1989). In the same way, the sea level around Lampedusa can be estimated by operating a local oceanic model that can be adjusted by the nearby tide-gage data and a mean sea-level surface reduced from Geosat data. Institut de Mécanique de Grenoble (IMG) has developed such a model and adapted it to the Lampedusa tide-gage configuration. This interpolation method has the advantage of providing a solution even if all on-site instruments are not operating (the error budget then being degraded). Moreover, the calibration itself can be extended to points other than Lampione as long as they are tied to the reference level.

3. Error Budget

Based on preliminary results of the oceanic circulation models around Lampedusa and simulations issued from short-arc techniques, an error budget for the calibration at Lampione was estimated (Table IV-1) for a 6-month calibration (assuming 10 passes over Lampione). This budget is imperfect, but indicative. It assumes that the laser at Lampedusa is continuously operational. The POSEIDON altimeter random error is deduced from simulations but was confirmed by ALCATEL company tests on the altimeter model (Raizonville et al., 1991). This budget is separated into a random part, which can be reduced by the number of calibrated passes, and a bias-type error (a true constant), which is incompressible and which is mainly due to the GPS leveling between Lampione and Lampedusa. (Other possible bias-type error sources, such as those due to media effects, were not considered here as it is not obvious that they are really constant.) Other points should be considered:

- (1) The error budget is given for $H_{1/3}$ values of 1 and 2 m—the wave-height averages during summer and winter at Lampedusa, respectively. The sea-state bias error is the result of an uncertainty equal to 1% of the $H_{1/3}$.
- (2) All the error sources uncorrelated between two consecutive calibrated passes over Lampedusa (10 days' separation) are considered random errors. These errors are thus reduced by averaging over several passes.
- (3) The POSEIDON altimeter noise level is averaged over 3 seconds because of the inter-

polarization (over 3 points seems a good compromise) of the altimeter measurements at the calibration point. This noise is the rss added to the short- and midterm errors of the altimeter.

- (4) The satellite position accuracy is based on a short-arc technique, but with a laser systematically operating at Lampedusa. The deficiency of the laser at Lampedusa degrades the error budget for the satellite position determination (4 to 5 cm of uncertainty if short-arc simulations are used (Biancale et al., 1989)).
- (5) The troposphere error is evaluated by measurements from a meteorological station and an upward-looking radiometer operating at Lampedusa. The ionosphere error is based on the processing of GPS and DORIS data collected on the site.
- (6) The GPS leveling is required to tie measurements from the tide gages to those from the laser station. The mentioned error corresponds to a distance of 22 km between the Lampione tide gage and the Lampedusa laser station. This error source is one of the more disturbing because it is bias-type error indistinguishable from the altimetric bias itself. To reduce this error, baseline accuracy was taken as 0.2 ppm of the baseline norm. This implies performance of the GPS campaign with all the required improvements.
- (7) Tide-gage precision has been estimated according to the specifications of the instruments used for the campaigns (Figure IV-2, Lampione tide gage No. 3).
- (8) The random error can be reduced by the number of calibrated passes. According to weather statistics, a total of six passes is expected to be successfully tracked by the Lampedusa laser during summer and three during winter. This estimate is based on a total of 10 Lampione overflights with the POSEIDON altimeter ON during the 6 months of the verification period (cf. Antenna Sharing Plan, Subsection I.5.).
- (9) The total error is the sum of the bias-type and random-type errors. For a 6-month campaign spread over the summer and winter (e.g., August and January), we can consider a mean

random error of 3.02 cm deduced from five expected calibrated passes (= 1.35 cm). This gives a total error (bias + random) of 1.74 cm.

This error budget needs to be completed. The results of the 1991 precampaign (September to November) at Lampedusa should allow a more detailed and more consistent error budget.

4. Instrumentation

Complete instrumentation will be set up on the Lampedusa site to provide optimum local control of the altimeter system, including data on sea level, geophysical corrections, and orbit (Figure IV-2).

a. Sea-surface instrumentation. Sea-level monitoring will be provided by a tide-gage network installed around Lampedusa. The instrument configuration was designed by taking into account the results of the SBS study on the oceanic environment, and, after two visits at Lampedusa during which all the potential tide-gage sites were inspected, the final selection was made.

Three coastal tide gages will be installed, one in Lampione, one southwest of Lampedusa near Cala Conigli, and one southeast of Lampedusa at Cala Croce. In addition, one seabed tide gage will be sealed (if there is no technical impediment) and placed 60 m deep on a rock 15 km south between Lampione and Lampedusa, under the TOPEX/POSEIDON track.

The selected coastal tide gages are the Aanderaa WRL-7 type (provided by CNR-ENEA) that measure sea level with an accuracy of 0.5 cm along with temperature and density. They will be equipped with an ARGOS station to allow automatic data transmission and high-frequency sampling at 2-min intervals as the TOPEX/POSEIDON satellite passes overhead. A pressure sensor placed at the ARGOS station measures atmospheric pressure. The seabed tide gage will be a SUBER type (provided by Etablissement Principal de la Service Hydrographique et Oceanographique de la Marine (EPSHOM)).

The technical implementation of the tide-gage network at Lampedusa will be conducted by the SBS with the support of Italian scientists (CNR-ENEA). This includes a laboratory calibration of all the tide gages in the basin of CNR-ENEA at La Spezia, Italy, a 2-week test at sea, and the installation of the instruments at Lampedusa.

In addition, density conductivity/temperature/depth (CTD) profiles (one per week) will be performed to connect bottom pressure measurements with coastal tide-gage data.

Hydrodynamic models (IMG support) will complete this sea-level monitoring system. Finally, the German group from the Institute of Astronomical and Physical Geodesy (IAPG) in Munich has proposed to moor buoys equipped with GPS receivers 7 km and 15 km south of Lampione under the TOPEX/POSEIDON satellite track. These buoys will measure sea-level variations with centimeter accuracy. Such buoys have already been tested with success in the North Sea area.

b. Satellite tracking systems. Lampedusa Island is part of the Wegener-Medlas network and is regularly visited by one of the mobile laser stations working for the program (MTLRS1, MTLRS2, or TLRS1). A platform was constructed for the laser installation at the middle west of the island. During the Lampedusa campaigns, the German system (the MTLRS1 station) will be installed from August to December 1992, in accordance with the calendar of the Wegener-Medlas program.

There is also the French ultramobile laser station, which is being developed by CERGA (with support of Institut Géographique National (IGN), CNES, and Institut National des Sciences de l'Univers (INSU)) and will be available for the mid-1992 campaigns. This station is a small and lightweight system requiring just 2 kW of power. It will be installed on the Trapani site (Milo, in Sicilia) near the backup verification site of Marettimo during the 1992 Lampedusa campaign.

Other surrounding laser stations (e.g., Grasse and Matera) will complete the Lampedusa tracking system and will be used in the short-arc computations. A DORIS beacon will also be installed at Lampedusa to improve the orbit tracking and make the ionosphere correction determination. A local GPS survey will be performed by IFAG to tie the tide gages to the laser station and DORIS station. A long-baseline GPS campaign was performed by IFAG in October 1991 to collocate the laser sites of Grasse, Matera, Milo, Noto, Punta Sa Manta, and Lampedusa.

c. Additional instrumentation. One meteorological station (provided by CNR-ENEA) will be placed on Lampedusa to measure atmospheric pressure, temperature, humidity, and wind. A GPS receiver (from Centre National d'Etudes de Télécommunications (CNET)) and a DORIS beacon installed at Lampedusa during the campaigns will be used to improve the local total electron content (TEC) knowledge.

Other instrumentation includes the PORTOS radiometer developed by CNES. This radiometer has six frequencies, two of which (24 and 36 GHz) are dedicated to the water-vapor content measurement. This instrument was

delivered by the MATRA company to CNES at the end of 1991. It will work on the ground in an upward-looking position and will be adapted next for airborne campaigns. This radiometer, installed in 1992 at Lampedusa, will measure the water vapor above the island to provide accurate wet-troposphere calibration data. Other upward-looking radiometers (e.g., the Centre de Recherche en Physique de l'Environnement/Along-Track Scanning Radiometer (CRPE/ATSR) engineering model and the JPL/WVR ground-based radiometer) will also measure water-vapor content at Lampedusa.

d. Data transmission. The other important issue concerns the transmission of the data collected at Lampedusa to the CAL/VAL center at CNES/GRGS. Measurements by the three coastal tide gages being equipped with an ARGOS station will be sent automatically via satellite. (The internal gage recorder is, however, maintained as a backup.) The ARGOS transmission has the advantage of operation without human intervention. Other sensor data collected on the site and not transmitted through an ARGOS station will be sent by telephone line. (Two persons will be present at Lampedusa during the 1992 campaign.)

5. Models

a. Hydrodynamic model. A model to predict sea level around Lampedusa has been developed by IMG. It will resolve the effect of tides and sea-level variability due to atmospheric forcing. This model will be especially useful in interpolating the instantaneous sea level under the satellite track. A large-scale finite element model (33°N to 38°N latitude, 10°E to 14°E longitude) embracing the high-resolution model centered on the island (34°N to 36°N latitude, 11°8'E to 13°2'E longitude) will be run to provide the boundary conditions (Figure IV-3). Tide forcing of the local model will be provided by the large-scale model, and atmospheric forcing of the local model will be provided by the wind and atmospheric pressure of the Peridot METEO France model. The tide-gage time series collected at Lampedusa will be used to constrain and tie the model to the reference level. During the 1991 precampaign, the model was tested and adjusted to provide an operational version for the 1992 mission.

b. Geoid/mean sea level. Having an accurate geoid or mean sea surface around Lampedusa provides a way to interpolate the tide-gage measurements to points offshore. Unfortunately, the accessible gravimetric data in the Lampedusa region are too sparse for the required accuracy. Derived geoids show, however, that the geoid slope in the area seems regular and relatively flat in the east-west direction (in the north-south direction, this slope is about 2 cm per km). To have more information on the short

scales of the geoid, the contribution of altimeter mean sea surface is essential.

The information brought by the Seasat and extended repeat mission (ERM) Geosat data (with the 17-day repeat orbit) is important, but still not enough because of the 100-km-spaced satellite grid. Fortunately, the U.S. Navy agreed to release (through NOAA) the Geosat data of the geodetic mission 50 km around Lampedusa (12°E to 13°E longitude and 35°N to 36°N latitude). Data sampling is then between 1 and 5 km, giving access to the very short scales of the geoid (Figure IV-4). (The first computed mean sea surface (MSS) confirms the relatively flat topography of the geoid.)

c. Meteorological models. The meteorological model outputs will be provided by METEO France. These data provide atmospheric pressure, water-vapor content, surface wind fields of the Peridot model (every 6 hours with a grid of about 35 km), and the wave-height output of the VAGMED meteorological model. These fields will be used to constrain the predictive sea-level model (see above), to monitor environmental conditions around Lampedusa, and to improve the altimeter corrections (e.g., those for troposphere, EM-bias, and barotropic effect).

6. Processing

The GRGS CAL/VAL group will be responsible for gathering all the data collected on the site and for ensuring data processing through internal or external (expert-group) analysis. The output of this processing will include bias, drift of the system, and an estimate of the TOPEX/POSEIDON altimeters' cross-calibration. The altimetric data will be extracted from SDR and IGDR files.

The tide-gage data will be analyzed and interpolated using programs developed at IMG, EPSHOM, and GRGS to estimate the undertrack sea level. Laser data will be processed at IFAG, CERGA, and GRGS using both overhead and short-arc techniques to provide the satellite's radial positioning over Lampedusa. The tide gages will be tied to the laser station by GPS leveling (IFAG). CRPE will participate in the water-vapor content measurement analysis to provide the wet-troposphere correction. CNES and CNET will analyze GPS and DORIS data to estimate the ionosphere correction. The altimeter data will be analyzed at GRGS, which will perform the synthesis (the closure equation) to determine the altimeter bias and associated uncertainty. Cross-calibration of the TOPEX and POSEIDON altimeters based on the verification site results will also be attempted.

All data will be processed and analyzed within 20 days after the Lampedusa overflight. The raw data, the processed data (geophysical data), and the results will be archived at CNES/GRGS. An extraction, including all the data over the Lampedusa site, will be made and systematically sent to the NASA/JPL verification team (Vincent and Montagne, 1991). This data set will also be available to Principal Investigators through a specific request.

7. Lampedusa Campaign Schedule

A preliminary campaign was held September to November 1991 (Figure IV-5). The main goals of this campaign were to test the instrumentation and the transmission systems in real conditions, to estimate the spatial correlation of the sea-level variations in the Lampedusa area, and to optimize the sea-level and tracking-data interpolation procedures. During this precampaign, three tide gages linked to ARGOS stations were installed at Lampedusa and Lampione sites, one seabed tide gage was moored south of Lampedusa, and one GPS buoy was placed at the vertical of this tide gage. Unfortunately, two severe storms caused the loss of one ARGOS station and the GPS buoy. The data collected during this precampaign are being processed at CNES/GRGS.

The postlaunch Lampedusa campaign should start in August 1992 (Menard, 1991) and extend to December 1992 (5 months after the satellite launch in early August 1992). The first month of the 1992 campaign (August) will be used to make all systems at Lampedusa operational. During this period, a calibration of the ERS-1 altimeter will be attempted because the ERS-1 satellite (in a 35-day repeat orbit) will then overfly the Lampedusa site. The instrumentation configuration of the site was optimized in accordance with the results of the precampaign and the TOPEX/POSEIDON track location (Figure IV-1). The IFAG mobile laser station will occupy the site from August to December 1992; the French mobile laser station will at the same time be at Milo (near Trapani in Sicilia) to track the satellite as it overflies Marettimo Island, which is an additional calibration site (see Subsection IV.A.8.).

Other campaigns of 2 to 3 months should be planned in 1993 and 1994 in accordance with the laser stations' availability. Such supplementary campaigns are needed for a better monitoring of the instrument drift. However, as long as the sea-level instrumentation (ARGOS tide gauges) is maintained, a continuous calibration activity can be foreseen at Lampedusa, outside the specific laser campaigns, just by using surrounding laser and Doppler data (a DORIS station could be maintained on the site) and short-arc techniques (even if the performance of the calibration is then degraded).

8. Other Verification Site Opportunities

Other sites will be used for the TOPEX/POSEIDON data verification.

There is, of course, the Harvest platform, which is the nominal calibration site under the responsibility of NASA/JPL. This site, which will be overflown by TOPEX/POSEIDON, will play the same role as that of the Lampedusa site (see Subsection III.A.). The data collected at this site will be sent to CNES by JPL for additional processing. In the same way, the Lampedusa data package will be sent by CNES to JPL.

Other sites of opportunity have been identified. There are oil platforms located in the Bass Strait region (between Australia and Tasmania) that have been proposed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) for TOPEX/POSEIDON measurement verification (see Subsection V.A.). South of England there are tide gages tied by GPS to the Herstmonceux laser station; these gages are close enough to the TOPEX/POSEIDON tracks for use as calibration points (see Subsection V.C.). Recently, there was a proposal by the University of Athens to use Greek Islands south of Dyonisos for verification.

CNES is performing a supplementary effort to use the Marettimo Island (20 km west of Trapani in Sicilia) as an additional calibration site (Figure IV-1). This small Italian island will be overflown by TOPEX/POSEIDON (ascending track) 12 hours after the Lampedusa overflight. It will be equipped with a tide gage and an ARGOS station to send sea-level data directly to CNES in quasi-real time. The French Station Laser UltraMobile (SLUM) will be installed during the first 6 months of the mission at Trapani (Milo platform) to provide (along with other surrounding laser stations) a precise orbit of the satellite as it overflies Marettimo.

B. Onboard Altimeter Tracker Verification

The CNES TOPEX/POSEIDON instrument team will verify the onboard tracker system by performing ground waveform analysis and simulations (Raizonville and Zanife, 1990). Tracker bias and noise will be estimated for such parameters as height, range rate, wave height, and σ_0 . The satellite attitude measurement will be compared to the estimate given by the waveform analysis. The spectra issued from the POSEIDON calibration modes (CAL1 and CAL2) will be used as inputs to the POSEIDON simulator to compute the lookup correction tables.

This ground-processing activity will be especially intense during the initial verification phase along all the POSEIDON passes overflying the verification sites and will concern the SDR high-rate and calibration-mode data. The ground retracking results of the altimeter return signal will be compared to the onboard tracking output. In the same way, the simulator will be run in various modes to compare its results with the onboard estimated parameters (especially the noise level). The initial lookup correction tables will be changed according to these results. The outputs of the waveform retracking will be provided to the GRGS group and will then be considered for use in the on-site calibration processing.

C. Statistical Analyses

Statistical analyses will be systematically performed on a global scale with the support of the AVISO center (Coutin-Faye, 1992) and the CAL/VAL-CLS team (Stum, 1991). These analyses are mainly based on crossover-point differences, global histograms, and comparisons with models.

1. Global Assessment of the IGDR at the Crossover Points

This section covers the analyses of residual heights at the crossover points (between ascending and descending tracks) using the various geophysical corrections present on the merged IGDR. The purposes of such analyses are to estimate the orbit error and to evaluate the performance of the altimeter corrections. The crossover-point files will also be used for the electromagnetic bias, the noise-level estimations, and the TOPEX/POSEIDON altimeter cross-evaluation.

For each cycle, the analysis outputs will include the total number of crossover points, the number of validated crossover points, the number of TOPEX/TOPEX (T/T), TOPEX/POSEIDON (T/P), POSEIDON/POSEIDON (P/P) crossover points (according to the working altimeter), and the number of rejected points with their mapping. At each crossover point, the geophysical parameters present on the IGDR will be interpolated (such parameters as altimeter measurement, TOPEX-based and DORIS-based ionospheric correction, TMR tropospheric correction, IGDR tide model, DORIS logistic 1-m class orbit, NASA preliminary orbit, and EM-bias correction when available), and the sea-level height difference will be calculated after application of the CNES nominal corrections to the altimeter measurement.

A color map of the crossover differences will be produced with statistics including a global histogram and

minimum, maximum, mean, and standard deviation of the differences. The maps and statistics will be performed for all the T/P, T/T, and P/P crossover points. These maps and information will be made available in the CAL/VAL bulletin (see Subsection IV.F.2.). The corresponding files will be accessible near the AVISO center.

Once every six cycles, this analysis will be completed by crossover-point mapping and statistics (producing the same outputs as those listed in the previous paragraph) on sea-level height residuals calculated with corrections and orbits different than those of the CNES nominal corrections and orbits, which include the NASA precise orbit, TOPEX altimeter ionospheric correction, Centre Européen pour les Prévisions Météorologiques à Moyen Terme (CEPMET) troposphere correction, and other EM-bias corrections. This will provide an easy way to compare the various corrections available on IGDR. Results will be provided in the CAL/VAL bulletin.

2. Estimation of the Electromagnetic Bias

The objective of this analysis is to provide for both altimeters the relation between the electromagnetic bias and such relevant parameters as $H_{1/3}$, σ_0 , and wave age. Based on the study carried out by Institut de Mécanique Statistique de la Turbulence (IMST) Marseille following several wave-tank experiments, the relation will provide a relative bias ($bias/H_s$), which should take into account the dimensionless significant waveheight ($g \cdot H_s / U^2$) that is related to the nondimensional fetch and to the wave age (Branger and Ramamonjisoa, 1991). The relation should have the following form:

$$bias/H_s = F(g \cdot H_s / U^2)$$

The coefficients of the relation will be determined by calculating the correlation of residual height with the interfering parameters at all the validated crossover points (see the previous subsection). This statistical analysis has been tested with success by using Geosat data (Gaspar, 1990). A first estimate of the EM-bias relation for the TOPEX altimeter should be issued after the first six cycles (and once every six cycles thereafter). However, the POSEIDON altimeter's working time is shorter and it will be necessary to wait longer to gather enough data on it to provide a significant result (a first result is expected after the first 3 months).

3. Estimation of the TOPEX/POSEIDON System Noise Level

This activity also uses the crossover-point difference analysis, but after application of a global mini-

mization by polynomial or sinusoidal adjustment. The main effect of this adjustment is to filter out the residual long-wavelength errors, such as those from orbit, atmospheric effects, and tides. After selecting the crossover points corresponding to short time lags between ascending and descending passes (to minimize the variations due to sea-level variability) in regions known for their low oceanic variability, the rms standard deviation will be calculated and associated with the $H_{1/3}$ and σ_0 parameters. This will provide a first estimate of the system noise level. This noise is called system noise because it includes residuals due to all components of the system (such as instrument noise, atmospheric corrections, orbit error, and sea-level variability). In this sense, it is different from the "pure" data noise level, which can be determined along track. This operation will be repeated for the different configurations: T/P, T/T, and P/P.

At each cycle, CAL/VAL-CLS will produce color maps of the residuals after minimization and their corresponding histograms for the different configurations (T/P, T/T, and P/P). A curve of the noise level as a function of $H_{1/3}$ and σ_0 will then be provided for each altimeter.

4. **Cross-Comparisons of TOPEX, POSEIDON, and ERS-1**

The issue here is to compare the sea-level heights obtained from TOPEX, POSEIDON, and ERS-1 measurements at the crossover points of the two satellites. This will be done at the end of the first 6 months by using one complete TOPEX cycle with a corresponding (in time) ERS-1 cycle and one complete POSEIDON cycle with the corresponding (in time) ERS-1 cycle.

The outputs will include a map of the rejected crossover points; a color map of the differences; the histograms; minimum, maximum, mean, and standard deviation of the differences; and a color map of the crossover differences after minimization, with the associated statistics. These outputs will be produced for the five configurations: T/T crossover points, P/P crossover points, ERS-1 crossover points, and T/ERS-1 and P/ERS-1 crossover points.

5. **Comparison Between the TMR and the ECMWF Correction**

This analysis consists in comparing the two tropospheric corrections (TMR and ECMWF) proposed in the IGDR files. The results should provide an estimate of the performance of each correction (e.g., systematic bias of the model and small-scale resolution by the TMR).

For the TMR correction, the ECMWF correction, and the difference between the two corrections, statistics will be calculated for boxes of 20° latitude by 20° longitude (this box dimension has to be confirmed); these statistics will include the histogram, the minimum, maximum, and mean values, and the standard deviation (Figure IV-6). This analysis will be carried out once per cycle. In addition, mean spectra of the two corrections and their difference will be computed over the same 20° by 20° boxes, but only every six cycles (to accumulate enough data for a significant result). Histograms and spectra will be mapped and included in the CAL/VAL bulletin (see Subsection IV.F.2.).

6. **Comparison Between the TOPEX, the DORIS, and the Bent Model Ionospheric Corrections**

This will be a comparison of the ionospheric correction issued from the dual-frequency TOPEX altimeter with the correction estimated from the DORIS data. The Bent model will be used as a benchmark to evaluate the performance of the TOPEX and DORIS corrections.

As for the tropospheric correction, statistics (histograms; the minimum, maximum, and mean values; and the standard deviation) will be calculated in boxes of 20° latitude by 20° longitude for the TOPEX and the DORIS corrections and their difference. These statistics will be performed for each cycle. Every six cycles, mean spectra for the two corrections and their difference will be computed in the same 20° by 20° boxes. The same computations will be achieved with the Bent-model-based corrections. These results will be mapped and included in the CAL/VAL bulletin.

7. **Blunder Point Detection**

This is an effort to detect the wrong altimeter measurements. These blunder points will be detected by testing the difference between the corrected sea-level height parameter and the mean sea surface present in the IGDR. The technique comprises the following steps (Benveniste, 1989):

- (1) Calculation of differences between mean sea level and altimeter sea level along half-revolution arcs.
- (2) Degree 2 polynomial approximation of these differences and calculation of the residuals with respect to this polynomial.
- (3) Detection of all the values higher than a fixed limit (about 3 m).

- (4) Operations (1) through (3) are repeated after elimination of the first detected wrong values (this is because the first polynomial approximation could be biased by these high values). A new test is performed with a lower limit (1.5 m, for instance).
- (5) If new apparent wrong values have been detected after the second test, the maximum along-track slope of the mean sea surface is estimated based on the six measurements taken before the detected point and the six measurements taken after. If the residual height of the detected point is higher than the maximum expected height—considering the estimated maximum slope—the point is definitely considered to be wrong (this is to compensate for the difference in resolution between the mean sea surface used as a reference and the altimeter measurements, and to avoid the elimination of points near sharp slopes of the geoid). A final test will consist in regarding the height deviation with respect to a spline passing over five consecutive points.

This procedure will be achieved for each cycle and for each working altimeter (TOPEX and POSEIDON). The corresponding outputs (published in the CAL/VAL bulletin, Subsection IV.F.2.) will include the number of wrong values thus detected and their location on a global map. A file of these blunder points can be made available through a specific request.

8. Estimation of the Along-Track Noise Level

This estimate of the noise level of the TOPEX and POSEIDON altimeter measurements is based on an along-track processing. It concerns the corrected sea-level height parameter. The method follows:

- (1) First, differences in the corrected sea-level height between two consecutive cycles are calculated by half-revolutions for a fixed period in the cycle (for instance from 220 to 246 half-revolutions). These semirevolutions are then cut off in 1000-km long arcs.
- (2) A Fourier transform is then applied along these arcs, thus providing a spectrum of the power density as a function of the wave number. This spectrum does not take into account the geoid effect and is weakly affected by the

oceanographic signal (as it concerns differences between consecutive passes).

- (3) The white-noise level of the altimeter measurement is associated with the constant part of the spectrum at short wavelength (around 50 km to 13 km). The mean value of this portion of the spectrum is calculated and integrated. The noise in centimeters is given by the root square of the mean multiplied by the root square of 2 (because this concerns the difference between two passes). For each arc 1000 km long, the noise level thus estimated will be correlated to $H_{1/3}$ and σ_0 parameters.

This estimate will be performed only once during the verification phase. Some characteristic spectra will be provided in the CAL/VAL bulletin (see Subsection IV.F.2.), along with the estimated noise level. For each altimeter, the evolution of the noise will be given as a function of $H_{1/3}$ and σ_0 .

D. Meteorological Product Validation

This validation of $H_{1/3}$ and the wind speed resulting from altimeter measurements will be made with respect to high-resolution models. The tasks will be performed by METEO France (Menard, 1991).

1. Validation of TOPEX and POSEIDON Wind Speed

Two objectives will be pursued: the calibration of the relation σ_0 /wind speed (for the two altimeters) and the validation of the wind speed estimated by altimetry.

This work is based mainly on comparison of altimeter data (σ_0 and wind speed) with the wind speed estimated by the models (ECMWF, ARPEGE) after a TOPEX/POSEIDON along-track interpolation. Such a study can be performed on a global scale or in specific regions where good quality in situ data (mainly buoys) have been collected (the model acts then as an optimal interpolator of these in situ data). The ERS-1 wind data should be assimilated in the models in mid-1992. This will provide an indirect way of global intercomparison of ERS-1 and TOPEX/POSEIDON data; the model is also considered as an optimal interpolator of ERS-1 data. In addition, regions can be selected for investigation by reason of their specific meteorological situations, this to check the performances of altimeter measurements in fronts, high sea-state, and low sea-state variability zones.

A first estimate of the altimeter-wind relationship and associated error budget will be provided by METEO France at the end of the first 3 months; a second estimate will be made 6 months after the launch. The result will have the form of σ_0/wind (table or analytic) relation. Histograms of the differences between models and altimetry will be mapped in boxes of 20° by 20° . Along-track comparisons will also be produced in some representative area.

2. Validation of TOPEX and POSEIDON Wave Height

This validation of the $H_{1/3}$ altimeter estimate will refer to the meteorological models VAGATLA (North Atlantic) and VAGMED (Mediterranean Sea). The method will be similar to that used for the wind. Specific regions of particular interest will be investigated; the regions will be selected on the basis of a special meteorological situation and/or the quality of the model estimates.

The first results will be provided by METEO France 3 months after launch and revised after 6 months. The results include an estimate of the ALT $H_{1/3}$ error and histograms of the difference between the model and altimetry using boxes 20° by 20° and along-track comparisons in representative zones.

E. CNES Precise Orbit Determination Validation

This validation will be driven by the satellite orbit determination (SOD). SOD will evaluate the very precise orbit (10-cm class precision for the radial component) and produce the results with a delay of about 25 working days (Laudet, 1991). (The logistic orbit, 1-m class, will be calculated with a delay of 2 days and will be included in the merged IGDR). SOD verification will be attached to the precise orbit production and will be based mainly on five components:

- (1) Overlapping ephemeris-arc differences. The nominal orbit will be calculated for arcs 10 days long. An additional orbit will be computed by arcs 10 days long, but shifted 5 days with respect to the nominal orbit. This will provide 5-day overlaps from which differences will be calculated; from these differences the mean difference, standard deviation, and spectra will be produced.
- (2) Laser residuals. Around the world, several laser stations (including Lampedusa, Grasse, and Matera) will be overflown by the

TOPEX/POSEIDON satellite. Selected passes (elevations $> 70^\circ$) of laser tracking data acquired by these stations will be obtained by SOD through the Crustal Dynamics Project Data Information Center (CDDIS) data bank. Residuals with respect to the CNES precision orbit ephemeris (POE) will be computed and interpreted in terms of orbit error.

- (3) Short-arc orbit comparison. For the needs of the on-site calibration (see Section IV.A.), short-arc orbits will be systematically computed by CERGA/GRGS in the verification site areas. These short-arc computations will include laser and DORIS tracking data available in a region of about 2000-km radius centered over the calibration sites. The orbits thus calculated will be provided to SOD, which will compare them with the POE CNES orbit.
- (4) NASA POE orbit comparison. NASA and CNES will exchange during the verification period complete arcs of the two precise orbits that have been computed at the source agency (NASA or CNES) with different data support (DORIS for CNES and laser for NASA) and different strategies. These two orbits will be compared by SOD to recover differences associated with orbit errors.
- (5) Crossover differences. The crossover points will be systematically computed for each cycle by AVISO (see Subsection IV.C.1.), but using the merged IGDR files that contain the logistical orbits. To evaluate the CNES final precise orbit before its delivery, the crossover-point files (with altimeter data and associated corrections interpolated at the crossover points) produced by AVISO will be provided to SOD. SOD will interpolate the final precise orbit at the crossover points and will then calculate the new altimeter residuals, which will give an additional orbit error diagnostic. The new residual files will be transmitted to CAL/VAL.

The outputs of this five-component analysis will be condensed in an orbit-error model that includes bias, mean standard deviation, time-space frequency analysis (spectra), and observed geographic correlations. These results will be transmitted to CAL/VAL for editing and publication in the CAL/VAL/AVISO bulletin.

F. CNES Synthesis and Result Report

1. Synthesis

Synthesis of the CNES verification will be conducted by the CNES project in association with the CAL/VAL-GRGS and the CAL/VAL-CLS groups. This work will follow regular working meetings (once every 2 weeks on average) with all the main groups (AVISO, CTD, SOD, and ALT expertise teams for the project side; METEO France, CNET, and CRPE for the expert external groups) involved in the verification process.

The synthesis will consist of gathering all the results obtained in the different domains, making a thorough analysis of these results, and interpreting the results in terms of the TOPEX/POSEIDON system parameters and error budget. The main significant results will then be selected, reported to the NASA verification team, edited in the CAL/VAL bulletin (see Subsection IV.F.2), and presented to the verification workshops.

2. CAL/VAL-AVISO Bulletin and Mailbox

The CAL/VAL-AVISO bulletin will be composed of checking forms for each type of correction and each geophysical parameter to be evaluated. These forms will include the significant values of the parameter (e.g., coefficients, bias, drift, mean error, standard deviation, and noise estimates), and they will be illustrated by the selected outputs of the various analyses (e.g., histogram maps, spectra, along-track comparisons, and crossover-point maps).

The main checking forms are the following: onboard system parameters, altimeter height measurement, ionospheric correction, tropospheric correction, electromag-

netic bias, precise orbit, sea-level height, wind-speed measurement, wave-height measurement, cross-comparison of TOPEX and POSEIDON, and the error budget. In addition to these forms, general information on the mission will be provided: distribution of the overseas and overland data, special events, significant changes in the system parametrization, and planning of the verification campaigns.

The bulletin will be edited once every 2 months and systematically distributed by the AVISO center to the PIs and CoIs on the TOPEX/POSEIDON data-distribution list. To complete the bulletin, there will be a permanent mailbox (OMNET?) that will quickly transmit special and important information to the TOPEX/POSEIDON data users. This mailbox will also serve the PIs and CoIs in sending their own information and/or making specific requests.

3. Verification Data Access

There will be a lot of outputs resulting from the different CAL/VAL activities listed in this section. However, to limit the weight and volume of the CAL/VAL bulletin, only the main CAL/VAL results will be published. The results listed but not presented in the bulletin will be accessible through a special request to the CAL/VAL group.

In addition to the bulletin, some global and statistical results will be made available on files. For instance, the crossover residual files will be accessible to the PIs through the AVISO Center channel.

All the in situ data collected at the verification sites of Lampedusa and Marettimo will be included, after preprocessing, in a specific package. This data package will be archived at GRGS. It will be sent out systematically to the NASA/JPL verification team and will be made available to PIs by special order.

Table IV-1. Error budget for the POSEIDON calibration at Lampedusa.

Error source, cm	Summer ($H_{1/3} = 1$ m)		Winter ($H_{1/3} = 2$ m)	
	Bias	Random	Bias	Random
POSEIDON altimeter		1.84		1.96
Satellite position	1.0	1.5	1.0	1.5
Troposphere (dry)		0.2		0.2
Troposphere (wet)		0.5		0.5
Ionosphere		0.5		0.5
GPS leveling	0.45		0.45	
Tide gage		0.5		0.5
Sea-state bias		1.0		2.0
Subtotal (rss)	1.10	2.72	1.10	3.30
Based on the number of calibrated passes out of a possible 10		6 passes, 1.11		3 passes, 1.90
RSS total error (bias + random)	1.56		2.19	

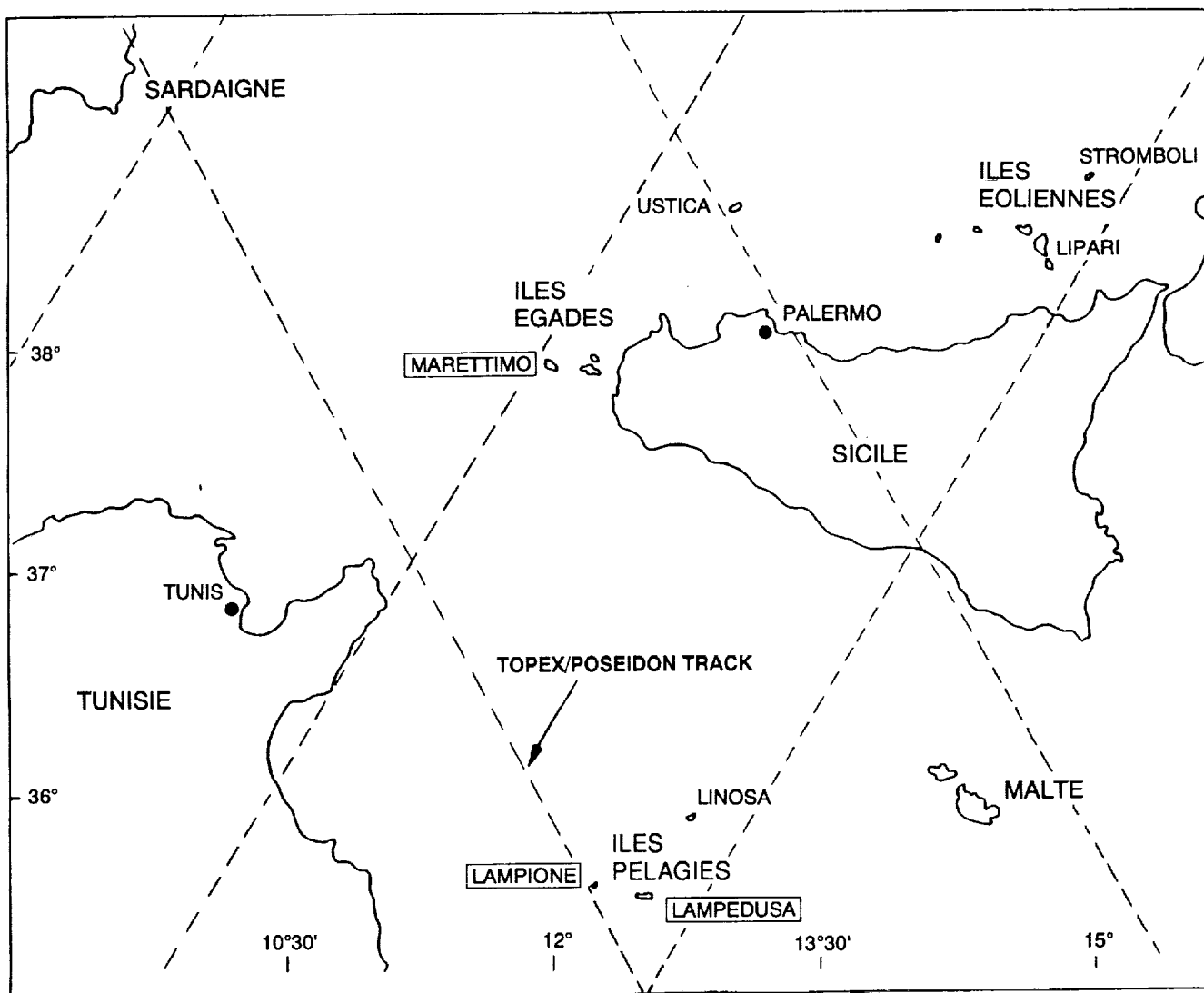


Figure IV-1. Lampedusa-Marettimo verification zone.

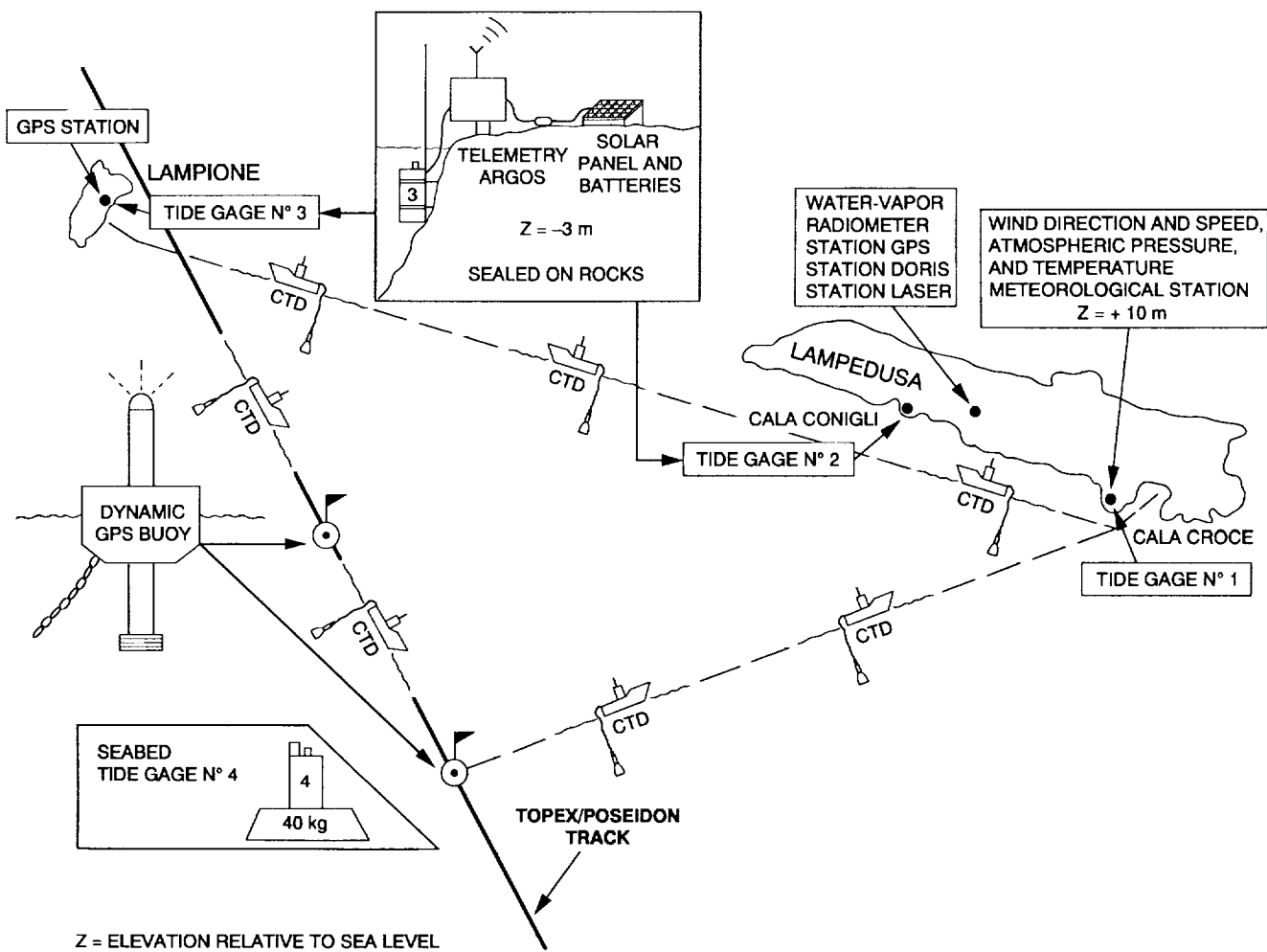


Figure IV-2. Instrumentation of the Lampedusa site.

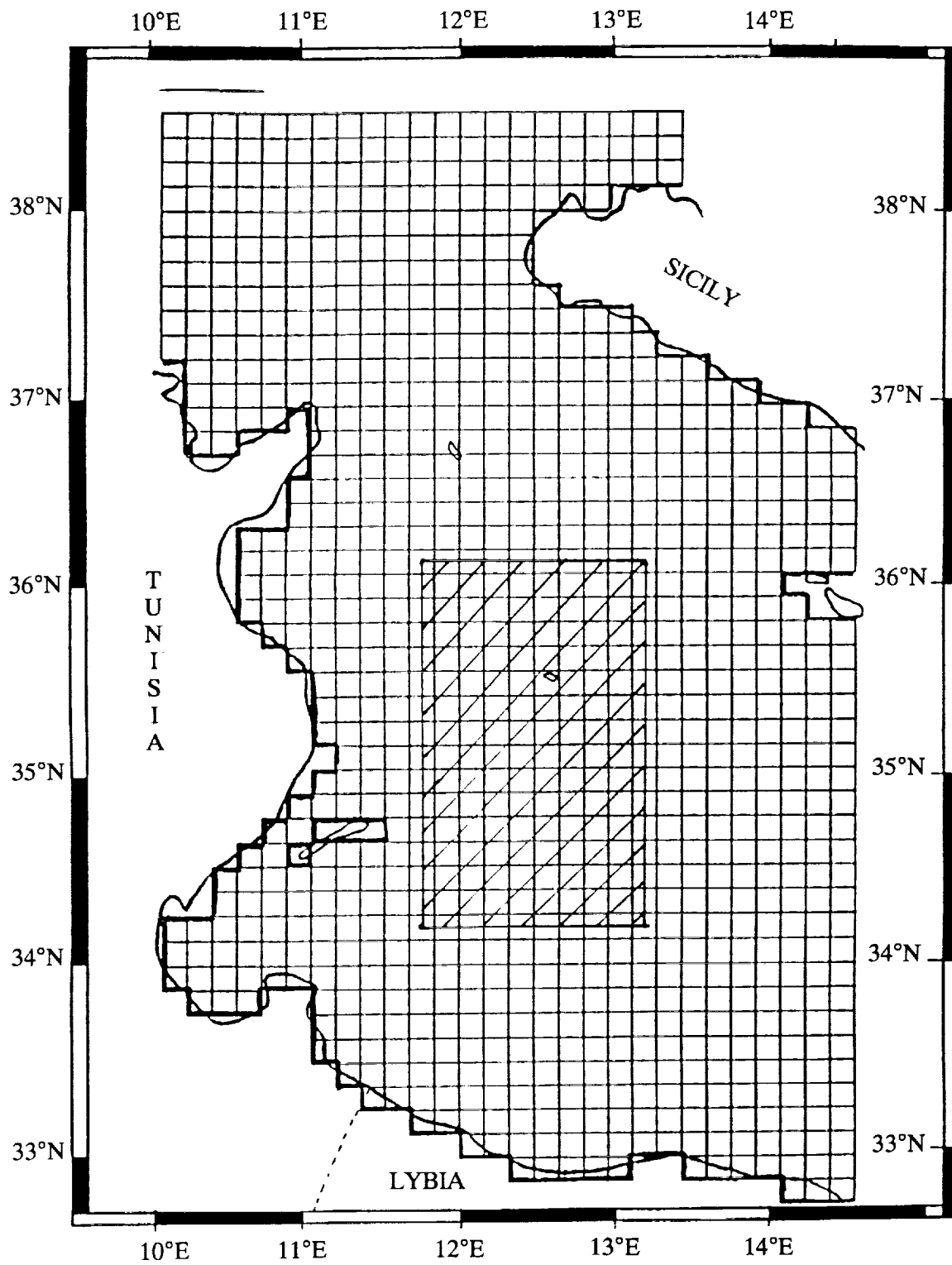


Figure IV-3. Situation of the local Lampedusa model with respect to the large-scale model.

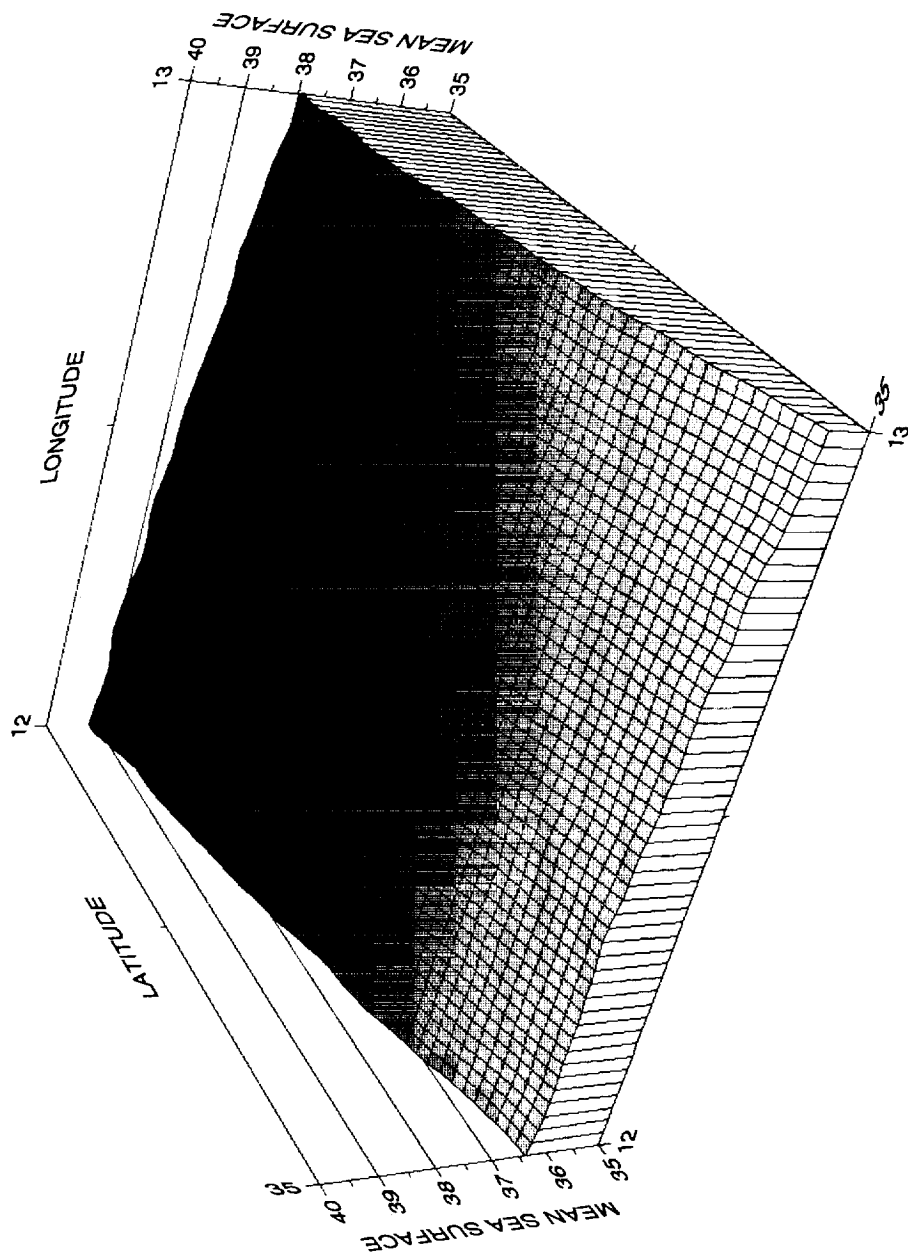
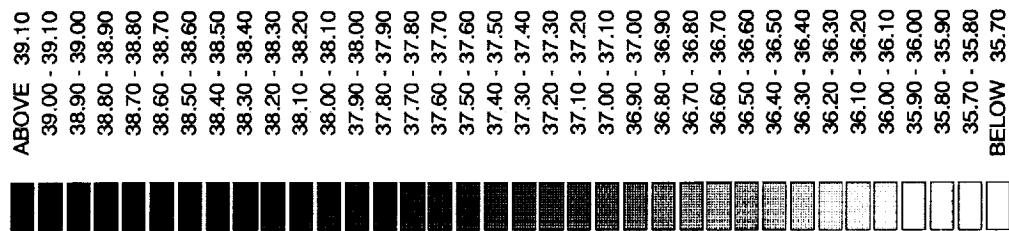


Figure IV-4. Geosat mean sea surface around Lampedusa.

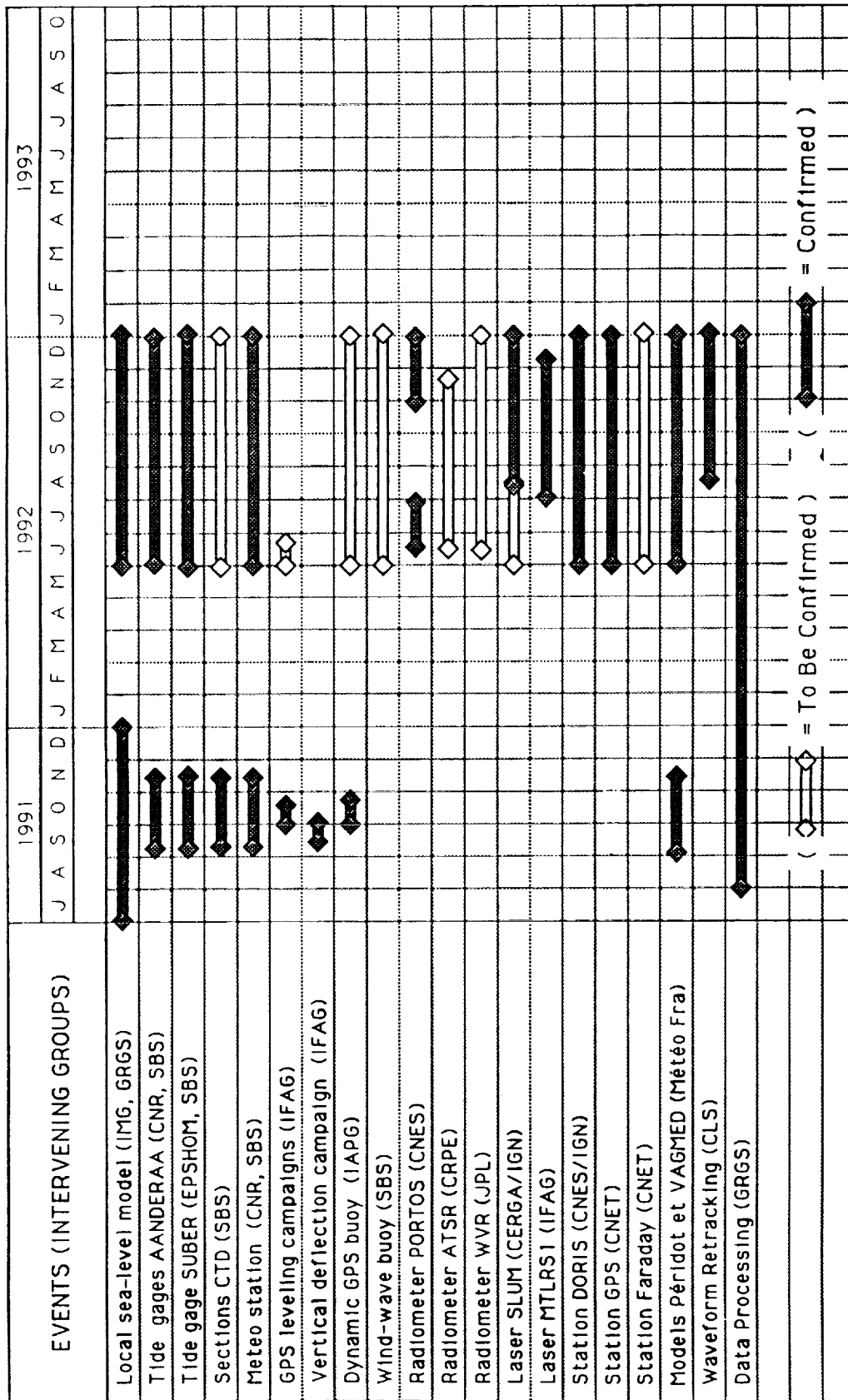


Figure IV-5. Lampedusa campaign schedule.

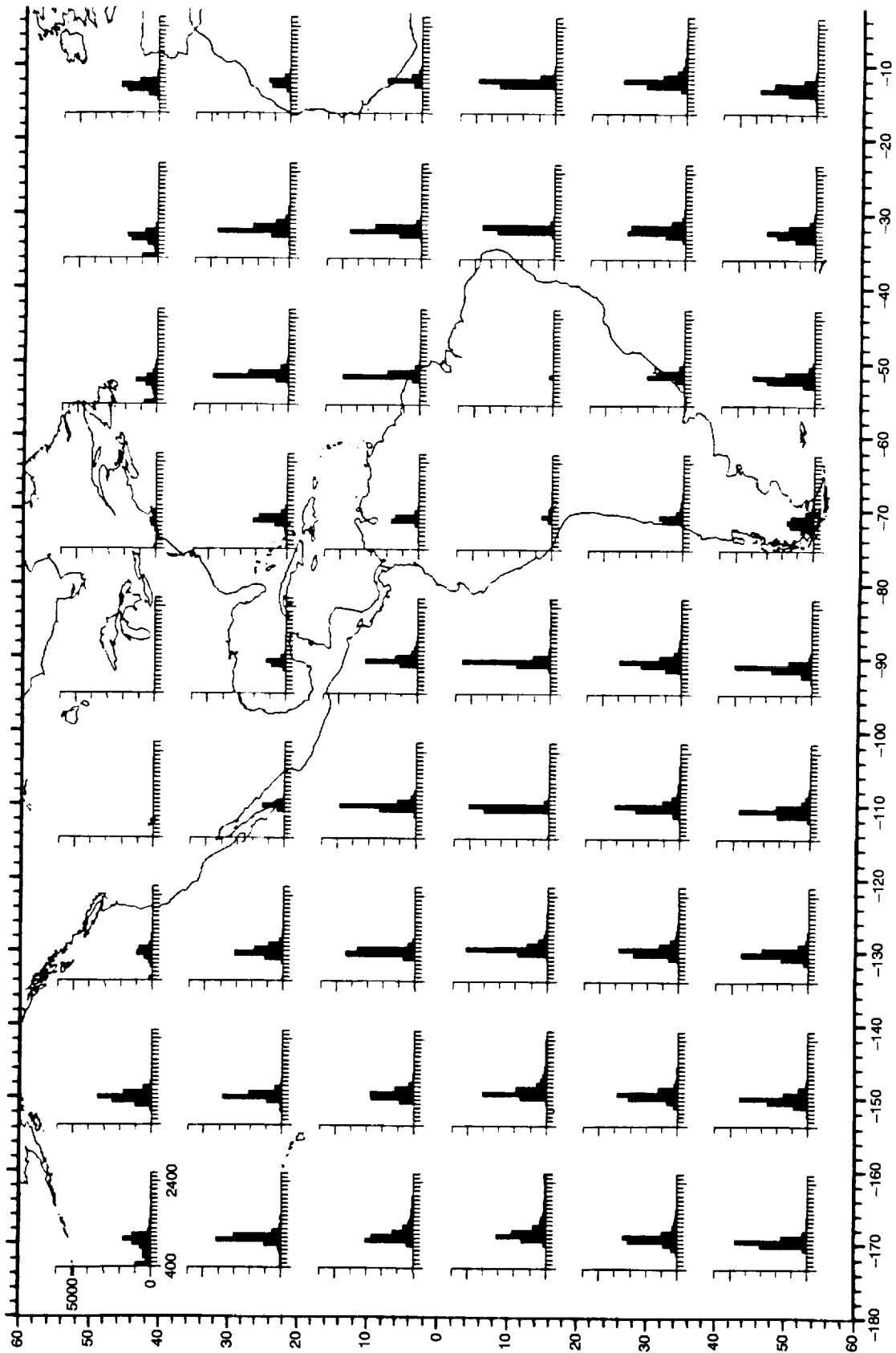


Figure IV-6. Example of statistical analysis: σ_0 histograms.

V. Science Investigator Activities

The principal objective of joint verification is to assess the performance of the TOPEX/POSEIDON measurement system, which includes the altimetric and orbit determination subsystems. To achieve this objective, the talents and resources of the project and science teams are pooled to form a Joint Verification Team (JVT). Investigators from programs outside of the TOPEX/POSEIDON Project have also been invited to contribute. The JVT will participate in the evaluation of the measurement system and will report its plans and findings at prelaunch and postlaunch JVT meetings organized jointly by NASA and CNES. This section provides a summary of the plans for each of the investigator groups that intend to participate in the JVT (see Table V-1).

A. Bass Strait Verification for TOPEX/POSEIDON: N. White, J. Church, and R. Coleman

1. Overview

The initial verification period for the TOPEX/POSEIDON altimeter will be the first 6 months after launch—from 1992 through to the end of 1992. In addition there will be smaller scale follow-up verification exercises throughout the mission. The satellite will carry two altimeters, a dual-frequency NASA altimeter and a single-frequency CNES altimeter. The two principal verification sites are at Point Conception, California, for the NASA altimeter and the island of Lampedusa in the Mediterranean Sea for the CNES altimeter. Both sites are in the midlatitudes of the Northern Hemisphere.

In view of the problems with the GEOSAT altimeter in the Southern Hemisphere—problems due to poor orbit data and poor environmental corrections (especially in the Southern Ocean)—it is important that there be some verification of the altimeter data in the Southern Hemisphere. (There has never been a calibration site for an altimeter in the Southern Hemisphere before.) For this purpose, we plan to use one or two sites in Bass Strait: the Snapper oil platform and Burnie on mainland Tasmania. The Snapper site is by far the superior site of the two, but the Burnie site should also give useful information. The Snapper site is also the more logistically difficult and expensive. If the Snapper site is approved, it will be the most accurate and most complete verification site in the Southern Hemisphere. The altimeter will pass over each site once every ten days. As the verification period will begin in the southern winter, the Bass Strait site should provide large $H_{1/3}$ values. During the winter months, wave height exceeds 1.7 m 50% of the time with some extreme

events to 9 m. If funding for the Snapper site is secured, the Burnie site may not be instrumented.

The CNES altimeter will be on for three passes out of five over the Snapper site during the verification period and the NASA altimeter will be on for two passes out of five.

2. Participants

John Church, CSIRO Division of Oceanography	TOPEX/POSEIDON PI
Neil White, CSIRO Division of Oceanography	Overall coordination and data analysis
Richard Coleman, Sydney University	Surveying, datum, and geoid
Elizabeth Essex, LaTrobe University	Ionospheric corrections
Fritz Brunner, University of N.S.W.	Ionospheric corrections
Bruce Rouse, Royal Melbourne Institute of Technology	Atmospheric water vapor
Edward Christensen, Jet Propulsion Laboratory	Orbits, water vapor

3. Region to be Investigated

Figure V-1 shows the Bass Strait region, the ground tracks of the passes in this area, the oil platforms, and Burnie. The Snapper site is 4.5 km from ascending pass 225 (equator crossing 165.1°E), and the Burnie site is directly beneath descending pass 88 (equator crossing 126.9°E). A brief description of the physical oceanography of Bass Strait is given in Subsection V.A.13.

4. Time Frame

We plan to instrument the Snapper platform before July 1992. The Marex tide gauge will stay on the platform after the initial 6-month verification phase. The radiometer will come off the platform at the end of this phase, but it or a substitute could be reinstalled for follow-up verification exercises.

5. Objectives

- (1) To verify the overall altimeter sea-surface height (SSH) measurement at the verification site.
- (2) To verify the various components of the SSH measurement: ionospheric corrections, atmospheric water-vapor corrections, atmospheric pressure corrections, and the altimeter range.

6. The Snapper Site

Due to the expense of fully instrumenting the Snapper platform (which is an oil and gas production platform), we propose to put a high-accuracy radar sea-level sensor on Snapper and use this data in conjunction with the data from the Kingfish B platform, which is more fully instrumented. The Snapper platform is about 4.5 km from the satellite ground track. The Kingfish B platform is about 30 km from the ground track at its closest approach and about 45 km from the Snapper platform (see Figure V-1). In addition, one or several bottom-mounted pressure gauges may be deployed directly under the satellite ground track. The sea-surface heights from the two oil and gas platforms will be used in conjunction with the CSIRO Division of Oceanography's shallow-water (wind and tide) models for Bass Strait to interpolate to the satellite ground track. This data will then be combined with the other information to give a calibration estimate for the altimeter. The Snapper site will give a good confirmation of the altimetry range and a number of environmental corrections.

7. Data to be Collected

- (1) Sea level.
- (2) Atmospheric water vapor.
- (3) Other meteorology.
- (4) Datum, gravity, and geoid.
- (5) Electron content of the ionosphere.
- (6) Orbits.

8. Instrumentation

a. Sea Level. A Marex radar will be fitted to the Snapper platform. This is an altimeter-type instrument mounted above the water (thus avoiding the prohibitive costs of any diving operations at the rig). Kingfish B is fitted with a Baylor wave staff and a Sea data 624XP tide gauge. As mentioned above, the data from these two instruments will be used in conjunction with the models to estimate the sea level under the satellite track.

It is anticipated that one or two bottom-mounted pressure gauges will be mounted near the Snapper platform. This would give a useful check on the other instrumentation, but would not give an independent absolute height because of the difficulty of surveying them to sufficient accuracy. Comparison with the Marex radar will give some estimate of a datum.

b. Atmospheric water vapor. Atmospheric water vapor is an important correction (the lack of working radiometers on Seasat and Geosat were major shortcomings for both missions). TOPEX/POSEIDON will have a microwave radiometer on board, and having ground-based measurements of atmospheric water vapor will act as confirmation of the satellite's radiometer.

The best way to measure water vapor is with a radiometer or radiosondes. We are hoping to borrow a radiometer from JPL. If this is not possible, we anticipate using radiosondes.

c. Other meteorology. The principal meteorological data (apart from the atmospheric water vapor) required are on atmospheric pressure. The data from Kingfish B and other nearby sites will be used. In addition, wind speed and direction will be recorded by personnel on both platforms. Wave height will be obtained from the Marex radar.

In addition, this pass lies directly over two waverider buoys off Cape Sorell in Tasmania (Figure V-1). The mean $H_{1/3}$ at this site is 2.7 m with very little seasonal variation, and the largest wave observed there in recent years was 17 m.

d. Datum, gravity, and geoid. Richard Coleman's group will survey the Snapper platform using GPS. One advantage of the Bass Strait region is an already thorough survey by Richard's group, so the task of surveying new instruments into the existing network is not substantial.

More gravity and geoid data are needed, both from Australian sources and from the classified part of the Geosat mission, to determine a higher quality gravimetric geoid.

e. Electron content of the ionosphere. Electron content of the ionosphere will be measured using GPS and Transit satellites in conjunction with other methods. Elizabeth Essex and possibly Fritz Brunner will carry out this work.

f. Precise orbit determination. The precise orbit determination will be made by JPL. JPL will provide us with the orbit data in PFILE or POE format, as well as software to read this data.

9. The Burnie Site

In addition to the Snapper site, we may place some instrumentation at or near Burnie. A descending pass will come off Bass Strait onto the Tasmanian mainland directly over Burnie. We propose to use a shore-based tide gauge at Burnie and/or a bottom-mounted pressure gauge. The above comments about the difficulty of getting a datum for a bottom-mounted instrument still apply.

This site is seen as a "second-order" site and will not give as good a calibration as the Snapper site. However, it would provide valuable independent information on the quality of the orbit determination if we go ahead with it.

Most of the environmental measurements will be similar to those for the Snapper site.

10. Analysis to be Performed

- (1) The respective groups will provide estimates of the environmental corrections.
- (2) JPL will provide POD data in PFILE format. We will also need some IGDR type data.
- (3) We will combine the datasets and verify the overall measurement and the various components of the measurement.

11. Data Requirements

- (1) POD data in PFILE format, or heights at the required times sent (possibly via Internet) from JPL.
- (2) Either IGDR data, or a subset of this for the required times (subsampled data could be sent via Internet).
- (3) Some POD- and/or IGDR-type data may be required from CNES.

12. Reporting of Results

Initially, results will be reported informally to NASA and CNES and more formally at TOPEX/POSEIDON verification meetings. We would expect a JGR-type publication to follow.

13. The Physical Oceanography of Bass Strait (from a science proposal by P. D. Craig, CSIRO Division of Oceanography)

Bass Strait is influenced by water masses from both the Great Australian Bight and the Tasman Sea (Newell, 1961; Rochford, 1957; Edwards, 1979). From the historical data, Baines and Fandry (1983) demonstrated the seasonal cycle of stratification in Bass Strait. In winter, intense wind- and tide-induced mixing combine with surface cooling to ensure well-mixed conditions. However, from November to April, surface heating causes stratification of the water column (away from the coastal margins) with the strongest stratification occurring during February.

Knowledge of the nontidal currents in Bass Strait is limited. In winter, drift bottle results (Vaux and Olsen, 1961), water properties (Newell, 1961; Edwards, 1979), and the northward flow of Bass Strait water at depth on the New South Wales continental slope indicate a net eastward flow through Bass Strait. During summer, increased stratification and the weaker and more variable winds make the situation less clear. There are indications, from surface temperatures and numerical modelling, that easterlies may drive a mean eastward flow. It can be inferred that there is a smaller flux of Bass Strait water into the Tasman Sea in summer.

In recent years, a number of current-meter moorings have been deployed in Bass Strait. However, the data base is sparse and many of the data remain unpublished. Most analyses have assumed that the nontidal currents are driven principally by the *local* wind. In support of this concept, Jones (1980) was able to show that near Kingfish B in eastern Bass Strait the nontidal currents were almost parallel to the local isobaths and their strength was about 2% of the wind speed.

Fandry (1981, 1982, 1983; Fandry, Hubbert, and McIntosh, 1985) has conducted a series of model simulations of Bass Strait. The model is depth averaged, with a horizontal resolution of about 15 km and has been used principally for tidal studies. However, wind-forced results agree with the observations of Jones (1980) and also show that a through-strait wind is more effective at flushing Bass Strait than is a cross-strait wind. The modeling also indicates that a westerly wind during winter can drive an eastward flow of about $3 \times 10^6 \text{ m}^3\text{s}^{-1}$ out from Bass Strait.

Using an array of current meters moored at the western entrance to Bass Strait during the period April to June 1984, Baines et al. (1989) estimated that the mean eastward flux through the western entrance of Bass Strait during this period was $0.5 \times 10^6 \text{ m}^3\text{s}^{-1}$. Surges of 2 to 3 days' duration

were found to accompany the passage of cold fronts through the region. The surges ranged between $3 \times 10^6 \text{ m}^3\text{s}^{-1}$ toward the east (corresponding to an eastward speed of about 20 cm s^{-1}) and $1.2 \times 10^6 \text{ m}^3\text{s}^{-1}$ westward. Their analysis indicated that about 3/4 of the forcing of the volume flux through the strait comes from the west of Bass Strait and that only about 1/4 comes from within Bass Strait. There is, however, no equivalent analysis for the summer period.

On the question of energy fluxes through Bass Strait, there is some contention. The results of the Australian Coastal Experiment (Freeland et al., 1986; Church et al., 1986a,b) have highlighted the importance of remote forcing and have shown that the east-west flow at the eastern entrance to Bass Strait generates coastal trapped waves that make a significant contribution to the variance of the currents on the shelf near Sydney. In an investigation of this forcing, Church and Freeland (1987) suggested that it was the winds within and to the west of Bass Strait that generate these coastal trapped waves. Clarke (1987), however, argued that very little of the energy of the coastal trapped waves generated in the Great Australian Bight actually enters Bass Strait. One consequence of Clarke's argument is that, contrary to the results of Baines et al. (1989), the currents at the western end of Bass Strait should be small.

The measurements of Schahinger (1987, 1989) indicate that the across-shelf scale of the low-frequency perturbations to the west of Bass Strait is considerably smaller in summer than in winter. This change may mean that currents are more closely trapped (in the form of baroclinic Kelvin waves) near the Victorian coast in summer, rather than occupying the complete north-south extent of the strait as found in winter (Baines et al., 1989). This may result in a greater coastal-trapped wave energy flux into Bass Strait during summer.

B. Regional Calibration Zone In the Western Mediterranean Sea: F. Barlier

1. General Overview

It has been proposed to define in the western Mediterranean Sea a regional zone for calibration and validation of some TOPEX/POSEIDON products, namely the altimeter calibration and the quality of the orbit determination. First the altimeter calibration will be performed locally at the Lampedusa/Lampione sites (by Y. Menard, P. Vincent, et al., GRGS/Toulouse), but the calibration and the validation could be controlled over all the mission in a regional manner and extended to other products such as the orbit determination, the altimeter corrections for various meteorological conditions, the absolute mean sea

level, and the precision of the mean sea surface. Presently, it is not yet possible to give the ultimate precision of such a calibration and validation because some contributing factors are not yet well known, but the objective is to reach an accuracy of about 5 cm, in any case better than 10 cm and if possible better than 5 cm!

For doing that, a precise geodetic network referred to the center of mass of Earth is being developed in this area and extended toward North Africa in the frame of the IERS and of the Wegener consortium. Presently, a partial geodetic network has been established, including SLR, very long baseline interferometry (VLBI) stations, and a tide-gauge network along the French Mediterranean coast and around Corsica. The precision is at the centimeter level but is still under evaluation (by C. Boucher and P. Willis, IGN). In this area, a mean sea-surface topography has been precisely determined with Geosat and Seasat data (by S. Houry and P. Mazzega, GRGS/Toulouse). Moreover, a modelling effort is being developed concerning

- (1) The tides (C. Le Provost, J. M. Molines, and P. Vincent).
- (2) Atmospheric effects (ocean-wind interaction based on the Peridot model from the French Met. Office) (A. Guillaume, J. M. Lefevre, and V. Casse).
- (3) The oceanic circulation: Euromodel (M. Crepon and C. Millot) and Mermaid model (P. DeMey et al.).
- (4) The sea seasonal flux variation, particularly well studied in the Ligure sea (J. P. Bethoux and J. L. Prieur).

As a result, the height of the sea surface could be well predicted as a function of time and compared to the altimeter measurement, yielding an estimate of the altimeter calibration all along the mission.

An important factor is still the link between the sea level defined by the tide gauge along the coast and the sea surface defined by the altimeter footprints. The sea surface has to be extrapolated towards the coast. For doing that as well as possible, a very dense network of tracks around each reference tide gauge, such as those provided by Geosat, would be extremely useful. Moreover, a hydrodynamic study should be performed in each case locally, taking into account the shape of the coast, the bathymetry, and the wind, as will be done at Lampedusa and Lampione islands (by J.M. Molines, Y. Menard, C. Le Provost, and P. Vincent.).

2. Participants

All the participants of the western Mediterranean proposal will be involved and will contribute crucially to the quality of the calibration-validation experiment.

For the quick-look analysis, the people involved directly in quasi-real time will be

- (1) F. Nouel et al. for the precise global orbit determination.
- (2) P. Exertier, P. Bonnefond, G. Metris, and R. Biancale for the regional orbit.
- (3) S. Houry, P. Mazzega, P. Exertier, P. Bonnefond, and P. Vincent for the sea-surface height.
- (4) A. Guillaume, J. M. Lefevre, and V. Casse for the atmospheric aspects.
- (5) P. Vincent and oceanographers for the oceanographic aspect.
- (6) S. Coutin for the data bank (AVISO).
- (7) Y. Boudon for the geodetic regional data bank.
- (8) F. Barlier, P. Exertier, Y. Menard, and P. Vincent for the synthesis.

3. Experiment Time Frame

The experiment could start as soon as the first data are available and will continue over the next 6 months. At that time, a conclusion will be drawn for the future. Results of the quick-look analysis could be delivered on a monthly basis.

4. Specific Objectives Regarding the TOPEX/POSEIDON Validation Issues

The main objectives are

- (1) Validation of the orbit determination.
- (2) Validation of the mean sea-surface determination.
- (3) Validation of the regional altimeter calibration.

5. Data Requirements for the First 6 Months

- (1) Regional tracking data (laser, DORIS).

- (2) Orbital elements from the global orbit.

- (3) Altimeter data (AVISO data bank).

- (4) Meteorological data (Peridot Model).

- (5) Tide-gauge data (problem still open).

- (6) Dense Geosat data around the tide gauges (problem still open).

6. Products Delivered Each Month

The products to be delivered concern mainly

- (1) The differences between regional and global orbit.
- (2) The altimeter crossover differences in the western Mediterranean Sea.
- (3) The differences between the predicted sea heights and the measured height.

C. TOPEX/POSEIDON Verification Activities Around the United Kingdom, In the Mediterranean Sea, and Over Land, Inland Water, and Sea Ice: P. L. Woodworth

1. Activity 1: TOPEX/POSEIDON Verification Around the United Kingdom Using POD from SLR, GPS Measurements, Tide Gauges, and Tide/Storm Surge and Geoid Models

a. General overview of the experiment. This activity, which has two elements, will be undertaken by the Proudman Oceanographic Laboratory (POL) and the University of Aston.

The first element has as its objective the verification of the corrected altimeter range measurement, simultaneous with and continued beyond the dedicated experiments at Harvest and Lampedusa. It will test the utility of offshore UK sites for long-term verification.

The proposal is, for each satellite track passing close to one of a subset of southern England tide gauges, to define a calibration point (CP) approximately 50 km from the shore. The 50 km is required to avoid land contamination in the TMR or altimeter data. In principle, the corrected altimeter range measurement should correspond to

- (1) Geocentric height of the spacecraft after various centre of mass corrections (from regional POD to be performed at the University of Aston).

- (2) Geocentric height of sea level at the gauge (from tide-gauge data and GPS measurements made by Nottingham University and POL).
- (3) Geoid difference gauge to CP (from a regional geoid model developed at the University of Edinburgh).
- (4) Ocean tide/surge difference (from tide/surge models run at POL and the UK Met. Office).
- (5) Load tide difference (from a POL regional load tide model).

The idea is to use one or two ascending and descending tracks to define a CP1 and CP2 for each gauge. There are six gauges within 200 km of the Herstmonceux SLR "fundamental point" in southeast England that have been surveyed with GPS in summer 1991 and that should be known geocentrically with respect to Herstmonceux to 1 to 2 cm. These are Newlyn, Portsmouth, Newhaven, Dover, Sheerness, and Lowestoft. It may be difficult to fit a 50-km distant CP into Dover, Portsmouth, and Sheerness in both directions, but perhaps nine CPs overall could be obtained. A preliminary calculation for the combined error budget suggests that a bias-error determination might be achievable to several centimetre precision for input to TOPEX/POSEIDON calibration studies.

The residuals from the calibration will need to be analyzed in terms of the errors in the corrected altimeter range (from such sources as ionosphere, troposphere, and wave bias) and in the measurements listed above. Regional models of meteorological variables and waves, for example, which are run routinely for other purposes, are as good as any worldwide and will be used to provide ancillary information as necessary.

The second element of this activity again uses precise regional short-arc orbits (or, alternately, the best DORIS orbits available) with the altimeter sea-surface heights for the North Sea and neighboring areas compared to the tide/surge plus geoid models. This is a version of the old SURGE verification for Seasat. The exercise would

- (1) Extend element 1 over a wider area, but with poorer precision. Also, as there would be no tie to gauges; any overall bias in the altimeter would be unobservable.
- (2) Validate the models further.
- (3) Lead to an evaluation of an eventual stage whereby altimetry could be assimilated into surge

models using predicted (or fast-computed) orbits plus geoid models in quasi-real time.

b. Participants in the experiment. The principal participants are Philip Woodworth, Trevor Baker, and Roger Flather of Proudman Oceanographic Laboratory, and Philip Moore of University of Aston. Also, collaboration will be requested from the Royal Greenwich Observatory (RGO) and Edinburgh and Nottingham Universities.

c. Region to be investigated. The northwest European continental shelf will be the focus of this study.

d. Experiment time frame. In principle, the experiment will commence as soon as possible using ERS-1 data. It will continue into the TOPEX/POSEIDON verification period and beyond, if desirable.

e. Specific objectives.

- (1) TOPEX/POSEIDON sea-surface height verification.
- (2) Validation of various regional models and POD techniques.

f. In-situ data.

- (1) Regional tide-gauge data and tide/surge model information.
- (2) SLR tracking information and computed orbits.
- (3) Geoid and load tide models.
- (4) GPS measurements at UK tide gauges.

All data obtained by POL and the University of Aston will be made available to other members of the project on request. Datasets and models obtained from the RGO, Nottingham, and Edinburgh Universities, will be made available given their permission.

g. Description of analysis methods. (See Subsection V.C.1.a.).

h. Data requirements. Several copies of merged IGDR data on CD-ROM will be needed as soon as possible.

i. Plans for reporting results. It is hoped that preliminary results will be available in time for the TOPEX/POSEIDON verification meeting approximately

6 months after launch. Final results will be published subsequently.

2. Activity 2: TOPEX/POSEIDON Verification In and Near the Tyrrhenian Sea Using In Situ and Aircraft Measurements

a. General overview and background of the experiment. Validation of TOPEX/POSEIDON is one of the objectives of the Tyrrhenian Eddy Multi-Platform Observations (TEMPO) programme, the wider purpose of which is to study upper-ocean structure and circulation of the Tyrrhenian Sea and its response to atmospheric forcing. TEMPO is an international programme involving groups from UK, Italy, and Germany, and so far three field experiments have been held (October 1989, February 1990, and October/November 1991). Data from the last of these is to be used for ERS-1 verification.

The series of TEMPO experiments has been designed to provide a coherent description of the dynamics of the whole Tyrrhenian Eddy and its seasonal response to atmospheric forcing. As such, the experiments will provide a unique dataset of the region enabling, for example, quantification of the amounts of Levantine Intermediate Water and surface Atlantic Water entering the basin and the routes by which the major water masses are transported. The present database is completely inadequate for this purpose, particularly in the southern portion. By linking the results of these observations with a parallel programme of modelling, it will be possible to build more realistic models in which the physics and the boundary conditions are better defined and which can in turn assist in more effective experiment design. For understanding the overall circulation of the basin, a knowledge of the inflow and outflow from the Tyrrhenian basin and their seasonal variability is of fundamental importance. For this purpose, long-time current measurements will be carried out in the Corsica channel and in the Sardinian channel at various depths.

The proposed experiments also provide the opportunity to validate and exploit ERS-1 and TOPEX/POSEIDON data in a programme specifically designed for this purpose and in the rather special conditions of a semienclosed sea. Although European data centres will process ERS-1 data to Level 2, the proposed project will lead to the development of higher level products (multipass, multisensor) as a result of the synergistic studies that are planned.

b. Participants in the experiment. The principal participants are Trevor Guymer of the James Rennel Centre for Ocean Circulation, Karen Heywood, and a student from the University of East Anglia.

Collaborating institutes in Italy are ENEA, La Spezia (Vincenzo Artale); IFA, Rome (Lia Santoleri); ISDGM, La Spezia (Gian-Pietro Gasparini); Telespazio, Rome (Salvatore Marullo); and, in Germany, Institut für Meereskunde (IFM), University of Hamburg (Werner Alpers).

c. Description of the region to be investigated. The Tyrrhenian Sea is the deepest basin in the western Mediterranean and one of the most important in the general circulation of the western Mediterranean because most of the return flow from the eastern Mediterranean to the Atlantic may pass through this region. Because of its topography, however, it is isolated from other parts to a greater extent than the other western Mediterranean basins. Its exchanges with the other basins occur through the Corsican Channel, having a sill depth at about 450 m, and through the opening between Sardinia and Sicily, with a sill at less than 2000 m and a restricted cross-section below 500 m of depth. The flow at the Corsican Channel is unidirectional: it always moves towards the Ligurian basin with a marked seasonal variability that may relate to differential winter cooling between the two seas. This means that the only source of water for the basin is at the southern opening, while draining happens through the Corsican Channel and by recirculation.

The main horizontal patterns in the basin are largely rotatory as indicated by the geostrophic analysis of hydrographic data performed by Krivosheya and Ovchinnikov, which shows that the large-scale basin circulation is basically cyclonic and organized into two main structures bordering at about 40 deg north. This pattern is greatly complicated by other cyclonic and anticyclonic eddies on the mesoscale. Moen has indicated that, during late summer, the presence of the northern gyre can be related to the wind jet blowing from the Strait of Bonifacio. In addition, it appears that variations in the inflow (from the Sicily and Sardinia Channels) and outflow (through the Corsican Channel) exert a controlling influence on the shape of the gyre system. Thus, there is interest in making measurements to the south of Sicily within the TOPEX/POSEIDON validation area.

d. Experiment time frame. Ship time has been proposed for two cruises in 1992. The fourth TEMPO experiment is scheduled for May 1992, which, in oceanographic terms, is the "cold" season. TEMPO-5 is planned for November 1992 ("warm" season), i.e., during the TOPEX/POSEIDON verification phase, and will concentrate on the inflow region encompassing both the Sardinia and Sicily channels. Sometime in 1993 a further experiment may be mounted to examine the same area under different conditions.

e. Specific objectives (regarding the TOPEX/POSEIDON validation issues).

- (1) To use ship, buoy, and airborne scatterometer winds for calibrating and validating altimeter wind speeds; in particular to examine any dependence on sea state and performance at relatively high sea-surface temperatures.
- (2) To use a Waverider buoy for validating TOPEX/POSEIDON $H_{1/3}$.
- (3) To evaluate the accuracy of the wet tropospheric range correction by comparison of integrated water vapor from the TOPEX radiometer with that obtained from radiosonde profiles of temperature and humidity.
- (4) On the basis of CTDs, to assess, through moored current meters and Lagrangian floats, whether altimetric estimates of sea-level variations in the region are meaningful.

f. In situ data to be collected. Measurements planned include wind speed and direction, wind from a sonic anemometer, bulk and radiometric sea-surface temperatures, air temperature and humidity, radiosonde temperature and humidity profiles (for the atmospheric corrections to infrared and altimeter data), and surface radiative fluxes. During TEMPO-5, aircraft measurements are planned to measure surface winds and a normalized radar cross section using a rotating antenna C-band scatterometer (RACS); sea-surface temperature (SST) will be measured using an airborne infrared radiometer. Wind measurements will be made to coincide with ERS-1 scatterometer swaths, while radar cross sections and SST will be measured along ERS-1 and TOPEX/POSEIDON altimeter tracks.

A sonic anemometer buoy will be deployed to provide the wind stress at a fixed location as close to the sea surface as possible. The use of a directional wavebuoy will allow the effect of the sea state on the stress to be determined. (Radiometric measurements of SST and of the other surface radiative fluxes will also be made as part of a heat budget study.)

To complement the aircraft and surface meteorological measurements, a comprehensive set of subsurface data will be required. This includes hydrographic, Eulerian, and Lagrangian measurements, as in previous TEMPO cruises, plus (it is hoped) the use of SeaSoar and an acoustic doppler current profiler (ADCP). The hydrographic measurements

will consist of CTD/02 sections between the surface and 3000-m depth and discrete water samples at standard depths.

g. Availability. Data obtained by UK participants (mean surface meteorology and sea-surface temperature, the speed of high-frequency winds from sonic anemometers on the ship and a buoy, radiosonde profiles, buoy estimates of wave parameters, and subsurface temperatures from SeaSoar, if used) will be made available to the TOPEX/POSEIDON Project and Science Working Teams in return for TOPEX/POSEIDON supporting data. Data from non-UK participants is also likely to be available, but will have to be negotiated separately.

h. Requirements for TOPEX/POSEIDON data.

- (1) Near-real-time access to initial IGDRs for planning during cruise (i.e., access over electronic networks to the ship).
- (2) Merged IGDRs on CD-ROM as soon as possible.

Item (1) is required only during the cruise; item (2) is needed from 1 month before the cruise (i.e., a total of 3 months).

i. Plans for reporting results. By the time of the TOPEX/POSEIDON verification meeting 6 months after launch, the TEMPO-5 cruise will only just have finished. It should be possible to provide a preliminary assessment of the in situ data obtained by that time. Some wind and wave comparisons may also be available, if TOPEX/POSEIDON data have been transmitted to the ship during the cruise. Final results will be written for publication in the refereed literature.

3. ACTIVITY 3: MSSL/UCL TOPEX POSEIDON Verification Activities

a. General overview and background of the experiment. Using data from Seasat and Geosat, we have demonstrated that pulse-limited altimeters can provide valuable information over sea ice, tabular icebergs, inland water, and land. Applications of the data include the monitoring of sea-ice extent, iceberg melt rates, water levels in lakes, wetlands, and rivers, the mapping of lake geoids, the delineation of subtle watersheds, the measurement of desert dune heights, the measurement of surface moisture variations in unvegetated arid and semiarid regions, and topographic mapping in areas of low relief and slope.

Here we propose to extend work currently being carried out with the ERS-1 altimeter to include TOPEX/POSEIDON data. The main advantages of combining the two data sets are to achieve improved spatial-temporal sampling (especially valuable for sea-ice, iceberg, and hydrological studies) and to carry out direct comparisons to expose any inconsistencies that may exist in the various parameters derived. Since TOPEX/POSEIDON was not specifically designed for operation over nonocean surfaces, a critical first step in the process will be to evaluate the instrument's technical performances over the surfaces of interest. Our approach will be similar to that we are adopting with ERS-1 and will involve the production of "global" statistics concerning tracking performance (e.g., the percentage of in-lock data as a function of amplitude of surface type and topographic relief plus the analysis of detailed case studies).

b. Participants. The participants will consist of members of the Mean Sea-Surface Level (MSSL) Remote Sensing Group. It is not possible at this stage to provide a final list, but it is likely that those involved will include Chris Rapley, Duncan Wingham, Wyn Cudlip, Charon Birkett, Jeff Ridley, Seymour Laxon, Fiona Strawbridge, Justin Mansley, and Jeremy Morley (Ph.D. student). Additional Ph.D. and M.Sc. students are likely to participate.

c. Description of regions to be investigated. The production of global land performance statistics will require access to at least one complete 10-day orbit cycle.

In addition, detailed case studies will be carried out as follows:

- (1) Sea ice: southern ocean (details depend on season).
- (2) Lakes: Victoria, two to three selected closed lakes (this depends on orbit details still being sorted out).
- (3) Wetlands: Sudd.
- (4) Rivers: Amazon (not necessarily all crossings).
- (5) Deserts: Simpson Desert, Australia, and Libyan Desert.

d. Experiment time frame. The evaluation work will be carried out such that, depending on the availability of

data, preliminary results from the global study and individual case studies will be available for the verification meeting 5 months after launch. Additional evaluation work will continue throughout the TOPEX/POSEIDON Mission and beyond. We anticipate that the evaluation work utilizing the desert field data will be complete within 4 months of returning from the campaign (i.e., February or March 1993).

e. Specific objectives regarding TOPEX/POSEIDON validation activities. The specific objectives of the work proposed are as follows:

- (1) To obtain global tracking statistics (i.e., percentage in-lock) as a function of surface type and relief amplitude (over land).
- (2) To investigate and summarize causes of loss of lock.
- (3) To evaluate tracker and AGC behavior over nonocean surfaces and to identify and describe any forms of anomalous behavior.
- (4) To investigate and summarize reacquisition behavior.
- (5) To evaluate quantitatively the ability of TOPEX/POSEIDON to provide sea-ice extent, water levels over selected lakes, wetlands, and rivers, and its ability to provide height, roughness, and radar backscatter estimates over selected land sites.
- (6) To report on the impacts of TOPEX/POSEIDON nonocean performance with respect to sea-ice, iceberg, inland water, and land altimetry applications.

f. In-situ data to be collected; availability to project and the Science Working Team. We have recently applied for funding to carry out fieldwork to coincide with the JPL-Australian AIRSAR campaign in September and October 1992. If successful, we will carry out measurements of microwave 13.8-GHz vertical incidence backscatter, surface roughness, surface and subsurface moisture, and vegetation cover. GPS and theodolite surveys will also be completed. The field work will be performed at several test sites, including one in the northwest Simpson Desert close to areas where we have carried out similar work. The details of the site locations have yet to be finalized, but will be optimized for use with ERS-1, TOPEX/POSEIDON, previous altimeter data, SIR-C, and AIRSAR.

The processed results of the fieldwork will be made available to the TOPEX/POSEIDON Project and the Science Working Team (SWT).

However, the associated ERS-1, SIR-C, and AIRSAR data will be subject to the conditions of redistribution specified by their data sources.

Surface data associated with several of the lake case study targets will be sought from third parties. Once again, the redistribution of such data will be subject to conditions specified by their sources.

All other case study comparisons will be carried out relative to ERS-1 and past altimeter data (e.g., Seasat and Geosat).

g. Description of the analysis to be performed. Existing MSSL software and data sets will be used to determine the global tracking statistics as a function of elevation roughness index and surface type, both derived from the NCAR 10-arcminute GDEM.

MSSL "Altimeter Toolkit" software will be used to examine and evaluate the TOPEX/POSEIDON tracker, AGC, and acquisition-sequence performance over a variety of different surface types. The Toolkit will also be used to carry out the quantitative evaluation of performance over the case study test areas.

Data from the field sites will be reduced to provide inputs to the MSSL arid-land vertical-incidence backscatter model, which will be used to synthesize echo waveforms for comparison with the observed echoes from TOPEX/POSEIDON.

h. TOPEX/POSEIDON data requirements. The requirement is for echo data (SDRs), but with the high-precision orbit ephemeris merged. It may thus be necessary to take both SDRs and GDRs and to carry out the merging at the MSSL. As noted above, data from one complete 10-day cycle will be required for the global statistical study. Data from at least one pass over each of the case study targets will be required from each 10-day cycle throughout the evaluation period. Ultimately, the entire TOPEX/POSEIDON nonocean SDR/GDR data set is requested.

i. Plans for reporting results. The results of the work will be made available to the Project and SWT in the form of internal reports and presentations to a to-be-determined schedule. Permission to publish the results at conferences and in refereed journals will be requested.

D. Evaluation of the Sea-State Bias and Quick-Look Analysis: L.-L. Fu

1. Objectives

a. Evaluation of the sea-state bias. As stated in our original proposal for the TOPEX/POSEIDON investigation, we need to remove all the sea-state related biases before undertaking the study of the gyre-scale circulation. As a first step toward this goal, we plan to evaluate the performance of the altimeter tracker and its ground correction algorithms for both the NASA and CNES altimeters. The approach we will take is to analyze the waveform data from both altimeters and compare the results with those from the IGDR. The ultimate goal is to remove the tracker bias in an optimal fashion and make recommendations to the project on the algorithms to be used for the GDR production. After removing the tracker bias, we will then evaluate the EM-bias algorithm by analyzing the altimeter height, $H_{1/3}$, and σ_0 simultaneously. This work will be conducted jointly with Ernesto Rodriguez and in close coordination with the CNES and the Wallops altimetry teams.

b. Quick-look analysis. We plan to process the IGDR in a near-real-time operational mode to provide quick-look products for preliminary science analysis and use by the project for public information purposes. Gridded fields of sea level, $H_{1/3}$, and wind speed will be produced within about 10 working days after the reception of a complete cycle of pass files.

2. Data Requirements

- (1) To meet the first objective, we need the SDR for both NASA and CNES altimeters. To have an adequate data base for the analysis before the verification workshop, we need at least 3 days' worth of SDR from each altimeter about 90 days after launch.
- (2) To meet the second objective, we need to access the pass files electronically throughout the entire mission. To produce sea-level maps of useful accuracies, we need real-time access to the so-called definitive orbit that is more accurate than the IGDR orbit.

E. SEMAPHORE Contribution to TOPEX/POSEIDON Validation Activities: L. Eymard, P. Y. Le Traon, and C. Le Visage

1. Introduction

SEMAPHORE is an experiment based on three French scientific programs (SOFIA, FLORENCE, and

ROME), which will study the mesoscale ocean circulation and air/sea interactions. The aim of SOFIA, set up by the Centre de Recherche en Physique de l'Environnement (CRPE, Paris), the Laboratoire d'Aerologie (LA, Paris), and the Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER) (Paris) is to study ocean-atmosphere energy exchanges at scales below 50 km. FLORENCE is being conducted by the Centre National de Recherches Meteorologiques (CNRM, Toulouse). It will use inverse modelling methods to describe turbulent heat exchanges at the ocean surface from satellite observations. ROME is the result of cooperation between the BRESM team at the Service Hydrographique et Oceanographique de la Marine (SHOM) in Toulouse and the Groupe de Circulation Régionale at the Groupe de Recherche en Géodésie Spatiale (GRGS, Toulouse). The aim of the ROME project is to describe and model the mesoscale oceanic circulation in the northeast Atlantic.

The main purpose of SEMAPHORE is to generate a comprehensive atmospheric and ocean data set. The data will be used to

- (1) Document the basic physical processes controlling momentum and heat fluxes at the air/sea interface, and study how those fluxes aggregate at mesoscale.
- (2) Calibrate and validate new techniques to estimate those fluxes.
- (3) Describe and model the mesoscale circulation, as required by many meteorological, oceanographic, and related applications.

Another central objective of SEMAPHORE is to use, analyze, and validate ERS-1 and TOPEX/POSEIDON satellite data. ERS-1 and TOPEX/POSEIDON altimeter data will be assimilated in a quasi-geostrophic (QG) model on an operational basis as part of the ROME project. Particular attention will also be paid to the validation of altimeter data and to the validation of altimeter data analysis methods (e.g., orbit error reduction and mapping) and assimilation techniques. SEMAPHORE can thus be of great value for TOPEX/POSEIDON validation activities.

SEMAPHORE will be conducted in the Azores-Madeira area from July 1993 to November 1993 (Figure V-2). The dynamics of the region are dominated by the Azores front and the related current and mesoscale eddies. The instrumented area will measure roughly 500 km \times 500 km (31.5 to 36°N, 20.5° to 26°W) but additional observations (and modelling) will be done in a larger area (1000 km \times 1000 km) (27 to 37°N, 18 to 29°W).

2. Participants in the Experiment

The scientific coordinator for SEMAPHORE is L. Eymard (CRPE). C. Le Visage (SHOM), S. Platon (CNRM), and A. Weill (CRPE) are the coordinators for ROME, FLORENCE, and SOFIA, respectively. Others will be involved in the validation of TOPEX/POSEIDON for SEMAPHORE: P. De Mey (GRGS), E. Dombrowsky (CLS), F. Hernandez (Ph.D. student), B. Le Squire (SHOM), P.Y. Le Traon (CLS), C. Le Visage (SHOM) (hydrography, Lagrangian floats and drifters, and moorings), G. Caudal (IG CNET), B. Chapron (IFREMER), L. Eymard (CRPE), D. Hauser (CRPE), J.M. Lefebvre (METEO France), S. Planton (CNRM) (wind and air pressure measurements, radio soundings, shipboard microwave radiometer, RESSAC and ROWS radars, and wave buoy).

3. Instrumentation

The experiment will consist of two phases. These will be sufficiently spaced (three months apart) for two decorrelated ocean observation arrays to be implemented, with XBTs, CTDs, and floats to be released in each. The first phase will be in June-July 1993. The second phase will be the Intensive Observation Period (IOP) in October-November 1993, where coupled ocean-atmosphere measurements will be performed. The instrumentation relevant to the TOPEX/POSEIDON validation (altimeter range, $H_{1/3}$, and wind and atmospheric corrections) is listed below.

a. Altimeter range validation:

- (1) *Moorings.* Four subsurface moorings will provide 1 year of precise measurements of the vertical structure of the oceanic circulation. These will be placed at cross-overs of TOPEX/POSEIDON and ERS-1 tracks (Figure V-2). The uppermost current meter is at 200 m and will be used to validate and compare ERS-1 and TOPEX/POSEIDON data. In addition, a meteorological-oceanographic mooring at around 35°N, 25°W will be deployed from July 1993 to November 1993. This mooring should be a mooring of the subduction experiment (with the IMET package) and will be placed at an ERS-1 crossover point.
- (2) *Lagrangian surface drifters.* Forty Lagrangian surface drifters drogued at 150 m will accurately map the surface geostrophic circulation in the 500 \times 500 km² box.

They will be useful for validating altimetry and altimeter data analysis methods (e.g., orbit error reduction and mapping techniques).

- (3) *Hydrographic arrays.* Two expendable bathythermograph (XBT)/CTD arrays with a nominal resolution of 30 nautical miles will be deployed in the 500×500 km² box at 3-month intervals (June–July and October–November). An intermediate XBT array will be performed in between. Around 40 Rafois floats drifting at 2000 m will provide an estimate of the velocity field at a reference level. The two arrays should thus provide an accurate “synoptic” estimation of the absolute dynamic topography (barotropic and baroclinic components). Whenever possible, hydrographic sections along TOPEX/POSEIDON and ERS-1 tracks will provide direct validation.

b. $H_{1/3}$ wind–air pressure, and wet tropospheric corrections. The wave characteristics and local swell will be analyzed using a wave buoy and airborne radars (RESSAC and possibly ROWS), which will provide direct validation of altimeter $H_{1/3}$. Note also that wave fields during SEMAPHORE will be modelled with the METEO-France VAG model.

Thirty-five drifting buoys fitted with thermistor chains to investigate the thermal structure in the ocean surface layer will also measure air pressure and wind (data will be reported in real time through the Global Telecommunication System and will thus be used in ECMWF analyses). Together with the meteorological mooring, these measurements will be useful for validating altimeter winds. Air pressure measurements will enhance dry tropospheric and standard inverse barometric-effect corrections.

Radio soundings (from one or two ships; these data should also be reported in real time through the Global Telecommunication System) and a shipboard pointing microwave radiometer will allow a validation of altimetric wet tropospheric corrections.

4. Data Requirements

Near-real-time access to IGDR-T and P (pass files) from AVISO (throughout the mission) is required. Data will then be sent directly to ships using the International Maritime Satellite (INMARSAT) (to optimize the

instrumentation strategy). We will also need merged IGDRs as soon as possible. A full cycle of POSEIDON French altimeter data during the intensive phase of the experiment (October–November 1993) is also needed (we shall request this in a separate letter to CNES).

5. In Situ Data Availability

Data collected during SEMAPHORE will be made available to the TOPEX/POSEIDON Project and Science Working Team as part of the general database of SEMAPHORE in situ data. The exact content of the database and corresponding time delivery are not yet, however, defined. This should be done during the next SEMAPHORE meeting (September 1992, Toulouse). We will keep the TOPEX/POSEIDON Project informed.

6. Plans for Reporting Results

Initial comparisons with surface drifters and hydrography will be performed in near-real time and will be available at the end of 1993. Shipboard radio soundings and microwave radiometer data will be analyzed in a few months. Some wind and wave comparisons may also be available within this time frame. Final results will be written for publication in the refereed literature by the end of 1994.

F. Ocean Dynamics of the Nordic Seas Using Satellite Altimetry: L. H. Pettersson

1. General Overview and Background

Current knowledge of the properties of the water exchange between the Atlantic and the Nordic Seas is mainly of a qualitative nature. The inflow of warm saline Atlantic water through the Faeroe–Shetland Channel is an important salt and heat source for the Nordic Seas. This inflow, called the Norwegian Atlantic Current (NAC), hugs the Norwegian continental slope on its northward course and is characterized by considerable mesoscale activity with eddy scales between 20 and 100 km. There is also significant inflow over the Iceland–Faeroe Ridge, with the major part merging with the NAC in the Faeroe–Shetland Channel. The reverse flow is partly in the upper layer and partly as an overflow over the submarine ridges between Greenland and Scotland. The upper layer flow is dominated by the East Greenland Current. The nature of this exchange influences the dynamics of the Nordic Seas and constrains the upper water circulation of the North Atlantic, making the region important for studies on the oceans’ role in the global heat budget and climatic changes.

2. Participants

- (1) Nansen Environmental and Remote Sensing Center, Bergen, Norway.
- (2) Geophysical Institute, University of Bergen, Norway.

3. Objectives

The main objective of this project is to integrate the sea-surface topography as resolved by the two TOPEX/POSEIDON radar altimeters with model results and in situ data to get a better quantitative representation of the short- and long-term variations in the mesoscale ocean circulation of the Nordic Seas south of 66°N. This will require

- (1) Validation of the altimeter-derived sea-surface topography against numerical model results and in situ measurements.
- (2) Synthesizing an optimal geoid for the investigation area by combining data from the Geosat, ERS-1, and TOPEX/POSEIDON and using an independent estimate for the mean dynamic topography to isolate the geoid from the altimetric mean sea level.

It is expected that the results of this investigation will contribute significantly to our understanding of the interaction between the North Atlantic and the Nordic Seas and enhance our capacity for predicting the variability of the exchange processes and their possible impact on regional climate change in northern Europe.

4. Investigation Area

Two major areas are proposed for investigation and study within the framework of this project:

- (1) The sill and trenches between Norway, Scotland, the Faeroe Islands, Iceland, and Greenland—the northeastern Atlantic boundary to the Nordic Seas.
- (2) The Norwegian Coastal Current region and continental shelf areas.

Previous studies of the Seasat and Geosat altimeter height data from the Nordic Seas, including the region between Norway, Faeroe, Shetland, Iceland, and Greenland, have demonstrated the usefulness of the altimeter as a tool for monitoring oceanic mesoscale variability. It is also expected that around 1 year of ERS-1 altimeter data will become available before the launch of TOPEX/POSEIDON.

5. Time Frame

The investigations are scheduled for the period 1992 to 1995.

6. In Situ Data Collection

A number of ship surveys are planned within the investigation area under the Nordic World Ocean Circulation Experiment (Nordic WOCE). The first of these is scheduled for the period July 12–28, 1992, with the Institute of Marine Research's vessel, Johan Hjort. Data collected during these surveys, including hydrographic data using the SeaSoar and CTD samplers and current velocity profiles from the Acoustic Doppler Current Profiler (ADCP), will be analyzed and used in the comparison study.

7. Description of the Analysis

Preliminary investigations will use Geosat and ERS-1 altimeter data. The in-house data-processing package developed for the Geosat includes routines for repeat track analysis and crossover analysis. In addition, a routine to apply tide corrections from regional models has been implemented and results from two tidal models—the Proudman Oceanographic Laboratory model and the Gjevik and Straume Model—are available. Studies with Geosat data have shown that the choice of a tidal model can significantly affect the computed mesoscale variability, especially in the exchange zone between Iceland and Scotland.

Our approach to the validation problem is to combine the use of numerical model results and in situ data. Two models—a multilayered isopycnal model for the North Atlantic by J. M. Oberhuber (OPYC model) and a one-active-layer reduced gravity model for the western North Atlantic by L. P. Roed et al. (RG model)—are available for use in the investigation.

Dedicated runs with the models will be undertaken using grid spacing and integration time steps compatible with the altimeter sampling pattern.

The OPYC model computes sea-surface elevations explicitly, making the retrieval of sea-surface height rms variability and anomalies straightforward. For the RG model, the comparisons will have to be of the sea-surface slopes and eddy kinetic energies, which may be estimated from both the model upper-layer current velocities and the altimeter rms variability. The spatial two-dimensional correlation matrices of the altimeter height variability will also be compared against similar quantities from the OPYC model, taking into consideration the differences in the altimeter sampling pattern and the model grid setup. The feasibility of using model mean sea-surface topography to

isolate the geoid from the altimeter mean sea level will also be investigated.

A study of the relation between sea-surface temperature signatures from the ERS-1 ATSR and coincident altimeter measurements will also be undertaken as an additional validation of the altimeter data.

Validation against in situ data will take the form of comparison of sea-surface slopes computed from hydrographic sections and ADCP profiles along the altimeter ground track.

8. Requirements

Standard GDRs for the duration of the TOPEX/POSEIDON mission period.

9. Plans for Reporting Results

The results will be published in international refereed journals and technical reports, which will be made available to the TOPEX/POSEIDON Project.

G. NOAA TOPEX/POSEIDON Calibration-Validation Activities: R. Cheney and B. Douglas

Sea-level measurements from the TOPEX/POSEIDON altimeter will be evaluated through a variety of analyses.

1. Timing Bias

A series of global crossover difference solutions will be used to determine whether a timing bias exists. A value will be derived from each 10 days of data to determine the stability of the result. (For Seasat, a significant bias of approximately 70 ms was found, whereas timing bias values for Geosat were so small that the problem could be ignored.)

2. Sea State Bias

Collinear difference analyses will be used to solve for a sea-state bias. (For Seasat, a value of approximately 7% of $H_{1/3}$ was found, whereas a value in the range of 1 to 3% has been determined for Geosat.)

3. Altimeter Corrections

The various altimeter corrections (for tide, wet and dry troposphere, ionosphere, and inverted barometer) provided on the TOPEX/POSEIDON GDRs will be evaluated independently using global crossover differences.

4. Tide Gauge Comparisons

Using both crossover and collinear differences, a sea-level time series will be constructed in small areas adjacent to island tide gauges. By comparing the TOPEX/POSEIDON records to the in situ values, an end-to-end evaluation of the altimeter data is obtained. (For Geosat, rms agreement of 3 cm or less was obtained for records of less than 1 year in duration.)

H. Rigorous Open-Ocean Validation of TOPEX/POSEIDON Sea Level in the Western Equatorial Pacific: J. Picaut, A. J. Busalacchi, T. Delcroix, and M. J. McPhaden

1. Rationale

The TOPEX/POSEIDON mission is projected to yield a 2-cm sea-level accuracy for studying meso- and large-scale phenomena. Such an accuracy is a minimum to quantify low-latitude surface currents, owing to the vanishing Coriolis force toward the equator.

In light of the Geosat mission, all in-situ sea-level estimates will result in an error of 3 to 7 cm. These estimates rely on various techniques of measurement, which indeed are subject to specific limitations. Sea level, deduced from island tide gauge data, is contaminated by current-island and shelf effects. Dynamic height time series, obtained from mooring, XBT, CTD, and IES data, capture only the steric sea-level contribution. Moreover, the significance of the series is altered by technical constraints such as reference level, the use of mean TS, and inadequate time/vertical sampling. Thus, there is a fundamental difference between the anticipated TOPEX/POSEIDON accuracy and our present observational means for validation.

At the recent TOPEX/POSEIDON meeting in Toulouse (October 1991), it was quite obvious that the TOPEX/POSEIDON Project has no present plans for the validation of open-ocean sea-level variability. As a contribution to the TOPEX/POSEIDON Verification Phase, we propose an experiment which would provide sea-level measurements in the western equatorial Pacific with a 1-cm accuracy. It would be the only rigorous open-ocean validation study being sponsored by the TOPEX/POSEIDON Project. The experiment would be conducted during the 6-month Verification Phase. It would strongly benefit from the scientific and logistic aspects of the TOGA-COARE unprecedented ocean-atmosphere experiment (e.g., half of the total cost of the proposed experiment is already funded as part of TOGA-COARE).

Space agencies such as NASA and CNES are often criticized for their practice of launching hardware into space at the expense or elimination of adequate in situ validation. In recognition of this, NASA Headquarters management has stated that going into the Earth Observation Satellite (EOS) era there will need to be increased reliance on interagency and international collaboration and cost sharing. This is particularly acute for ocean remote sensing where the logistics of in situ validation could prove prohibitive. Our proposed efforts are in direct response to the need for rigorous open-ocean validation of the TOPEX/POSEIDON altimeter-data retrievals. By leveraging existing observational programs, there is considerable interagency and international cost sharing. If we were unable to exploit these existing programs in the western Pacific, the true cost of this validation effort would increase by \$300K and therefore would be cost prohibitive.

2. The Experiment

Two existing TOGA-Terre Atmosphère Océan (TAO) ATLAS moorings (Figure V-3), located at 2°S, 156°E and 2°S, 165°E, will be outfitted with additional dedicated instruments especially designed to capture sea level with a 1-cm accuracy at two TOPEX/POSEIDON crossover points. A series of surface-to-bottom temperature and salinity sensors along the mooring lines will provide the steric part of sea-level changes. The barotropic part will be deduced from bottom-pressure sensors. The atmospheric pressure effect will be estimated from surface-pressure sensors.

The two different sites are located in very different geographical settings. The 2°S, 165°E mooring is anchored on an abyssal plain (4400 m) far from a coast, whereas the 2°S, 156°E mooring is situated on the Ontong Java Plateau (1750 m) near the Kilinailau trench and at little more than a radius of deformation (400 km) from New Ireland and Bougainville islands. Sea-level intercomparison between these two different sites will provide essential information on bottom-induced barotropic and baroclinic effects and on-island, sea-mount, and trench geoid effects.

This is a critical experiment for the TOPEX/POSEIDON program, and the two sites are also necessary for redundancy in the event that one of the moorings is damaged or lost. Mooring losses are infrequent, but they nonetheless must be considered in designing any field program relying on moored instrumentation. In TOGA-TAO, over 30 moorings are presently maintained across the equatorial Pacific, and there are plans to expand this array to almost 70 moorings in the next 2 years. Loss of a single mooring in this array would represent only 3% of the data from the present array. For the TOPEX/POSEIDON validation study based on only one mooring, loss of that

mooring would represent 100% of the data. Moreover, mooring losses are generally higher in the COARE region than elsewhere because of intensive commercial fishing by nations bordering the western Pacific. Thus, to ensure that our efforts produce at least one 6-month validation data set from the western Pacific, it is essential to fully instrument two sites (with backup flotation and double releases on each).

Historical background exists for the 2°S, 165°E original site, because numerous cruise and ATLAS mooring data have been collected since 1985. The data gathered at this site were used to evaluate Geosat in 1986–87 and also in a statistical study for the proposed experiment. The 2°S, 156°E ATLAS mooring, installed in September 1991, has the advantage of being situated at the center of the COARE Intensive Flux Array. This array will provide unprecedented ocean-atmosphere measurements, especially during the Intensive Observation Phase (IOP, November 1992–February 1993). From the ocean side, the measurements consist mainly of temperature, salinity, current, and turbulence taken from ships (8 to 15), moorings (30), and drifters (approximately 50). In the atmosphere, temperature, humidity, pressure, wind, rain, and radiation will be measured from numerous instruments installed on islands, ships, dropsondes, airplanes, and satellites. All these data will be made available to the COARE scientists in a timely manner (3 to 6 months) after the IOP. The TOPEX/POSEIDON Project will have lost a tremendous one-time opportunity if it does not take advantage of this suite of measurements for validation in the western equatorial Pacific.

In August–September 1992, the 2°S, 165°E and 2°S, 156°E ATLAS moorings will be replaced during the SURTROPAC-17 and COARE 156-3 cruises on board the French R/V *Le Noroit* (the original 2°S, 165°E mooring will be shifted to 164.5°E under a TOPEX/POSEIDON crossing point). Both moorings will be completed with additional sensors along the line and surface- and deep-pressure gauges as needed for the proposed experiment. All corresponding data will be retrieved in March 1993, at the end of the French COARE-POI cruise. The timing of this experiment is thus concomitant with the TOPEX/POSEIDON Verification Phase.

The present design of ATLAS thermistor chain moorings includes 11 temperature sensors in the upper 500 m and a meteorological unit. The daily averaged data are transmitted via ARGOS and sent on GTS. Estimates of 0/500-dbar dynamic height, derived only from these temperature measurements, will be compared in near-real time with TOPEX/POSEIDON sea level. This proposed

work will be done for the 2°S, 15°E and 2°S, 164.5°E sites and also for the 30 to 50 TOGA-TAO ATLAS moorings located over the whole equatorial Pacific. However, due to the previously discussed limitations, these estimates of sea level will certainly result in a 4- to 7-cm error.

To obtain the 1-cm sea-level accuracy (total steric and pressure contributions), a series of additional temperature, salinity, and pressure sensors will be installed for the 2°S, 156°E and 2°S, 164.5°E sites, with 0.25- to 5-min time resolution to adequately resolve high-frequency waves. The number of additional temperature and salinity sensors is determined through a sampling study based on 13 (57) deep CTD casts made at (around) 2°S, 165°E over the last 6 years. Surface dynamic heights relative to the bottom are calculated from a series of discontinuous T,S points taken on the CTD profiles at the sensors' depths and compared to their values using the complete CTD profiles. Different calculations, made with various array designs, result in a standard error of 0.6 dyn cm for the following array. Because of important salinity variations in the first 500 m (Figure V-4), 10 SEACAT (T,S) units are needed between the ATLAS temperature sensors, themselves completed with interpolated salinity. From 500 m to bottom (1750 m at 2°S, 156°E; 4400 m at 2°S, 164.5°E), the salinity variations are small enough to use 7 (10) miniature temperature recorders (MTRs) and a mean T,S relationship. BPRs (bottom pressure gauges) will be installed near the two moorings and will result in a 0.3- to 0.5-cm barotropic sea-level accuracy, after pressure drift corrections. Flotation (Benthos) balls together with additional acoustic releases will complete the two ATLAS lines to recover all equipment (therefore the data) if the surface toroid happens to disappear because of vandalism, mechanical failure, or hurricane.

3. Participants

Although the participants are all members of the same TOPEX/POSEIDON scientific team, the intended validation experiment is separate from our existing TOPEX/POSEIDON science project and is submitted in recognition that the TOPEX/POSEIDON Project has no apparent plans for open-ocean validation of the TOPEX/POSEIDON altimeter retrievals. A notable advantage of the proposed work stems from the complementary backgrounds and expertise of the four participants (in situ and satellite observation analysis, and numerical ocean modeling) and from their ability to cooperate for the last 5 to 10 years.

Two members of the proposed work team have been for several years PIs of the TOGA-TAO mooring network in the western equatorial Pacific. This network, functional for TOGA objectives, was made possible by cooperation

between ORSTOM and NOAA/PMEL. Modelling, in situ, and satellite data intercomparison extended this efficient collaboration to NASA/GSFC.

All members are strongly involved in the TOGA-COARE field and model studies, which enable them to have unlimited access to the corresponding ocean-atmosphere data set.

4. Data Processing and Analysis

Temperature and salinity data from SEACAT units will be calibrated with CTD measurements taken during the TOGA-COARE experiment and processed at ORSTOM-Noumea. Data from the ATLAS thermistor chains, MTR, and BPR will be prepared at NOAA/PMEL.

Time series of TOPEX/POSEIDON sea-level anomalies provided by the TOPEX/POSEIDON Verification Team will be compared to sea level derived from surface-to-bottom dynamic height and bottom pressure time series. The relative importance of pressure and steric components will be studied in conjunction with water masses, ocean bottom, and geoid variations.

Empirical and theoretical mode decompositions will be performed to determine the major modes of variation in the vertical structure. Models will then be used to retrieve subsurface and deep-ocean information from TOPEX/POSEIDON sea-level measurements.

Precise and continuous (time/depth) unprecedented T,S data will provide fruitful information relevant to TOGA-COARE objectives (e.g., barrier-layer, heat, and salt advection).

Differences between TOPEX/POSEIDON sea level and our rigorous in situ steric and pressure sea level could be used by TOPEX/POSEIDON engineers to refine instrumental and geophysical altimeter calibrations using all atmospheric and oceanic data collected during TOGA-COARE.

I. TOPEX/POSEIDON Verification Activities Around Japan: J. Segawa

J. Segawa has submitted a Letter of Intention to join the JVT by conducting studies in the western Pacific zone.

J. University of Hawaii Sea Level Center Contributions to TOPEX/POSEIDON Verification: G. T. Mitchum

G. T. Mitchum has informed the TOPEX/POSEIDON Project that the University of Hawaii intends to conduct analyses using University of Hawaii tide-gauge data.

K. Kuroshio Experiment: J. Mitchell

J. Mitchell has informed the TOPEX/POSEIDON Project that his research team intends to perform a quick-look analysis in the Kuroshio region.

L. Upper-Ocean Heat and Momentum Budgets In an Eastern Boundary Current: P. T. Strub, C. A. Paulson, and R. D. Pillsbury

1. Introduction

The goal of our work is to increase our understanding of the heat and momentum budgets in the upper ocean within the California Current System. To accomplish this goal, two related activities have been funded as part of the Office of Naval Research's Accelerated Research Initiative (ONR ARI) on Eastern Boundary Currents: (1) a buoy will be deployed to measure meteorological forcing (surface fluxes of heat and momentum) and upper ocean response (profiles of temperature and velocity from the surface to 150 to 200 m depth); (2) fields of SST from the Advanced Very High Resolution Radiometer (AVHRR) satellite sensor will be collected during the 2-year period of current-meter moorings and field surveys.

2. Met/Upper-Ocean Buoy

The meteorological buoy will be placed at the center of the Local Dynamics Array (LDA), 450 km offshore under a TOPEX altimeter crossover point (see Figure V-5). It will be deployed between 4–10 August 1992 and will sample for 1 year (two separate 6-month deployments). It will measure wind speed and direction, air and surface water temperature, air relative humidity, and solar radiation. These data will be telemetered in real time, as well as recorded internally.

This buoy will also be equipped with miniature temperature recorders (MTRs) to measure water temperature every 5 m down to 150 m depth. A downward-looking ADCP will be mounted on the buoy by Teri Chereskin to measure water velocities down to 150 to 200 m. Although data from the ADCP and MTRs will not be telemetered, Dale Pillsbury plans to deploy an experimental current meter of his own design on the mooring at approximately 30 m of depth, which will be telemetered, providing some real-time current data. These measurements will allow analysis of the upper-ocean momentum and heat budgets and an investigation of the role, within those budgets, of horizontal eddy transports due to energetic mesoscale features.

The measured horizontal eddy transports will be compared with estimates of similar eddy transports made from satellite data. Satellite surface temperatures from the AVHRR will be combined with velocities from the ERS-1

and TOPEX altimeters to calculate eddy transports of heat in the upper ocean at the location of the mooring and over the large-scale California Current System. Velocities from sequences of AVHRR images will also be incorporated into the analysis. The statistical relation between the transports and the fields of surface heating, wind stress, and wind stress curl will be investigated, using winds from operational models and the ERS-1 scatterometer.

The question has arisen as to why the met/upper-ocean buoy should be located in the center of the offshore LDA, which coincides with a TOPEX altimeter crossover point, rather than in the center of the more inshore LDA, which is not under a TOPEX track (see Figure V-5). There are several reasons to pick the location under the TOPEX crossover.

Altimeter data will be used to calculate cross-track surface velocities and eddy momentum fluxes ($\overline{u'v'}$), with one sample every 10 days; these eddy momentum fluxes can be calculated only at crossover points, since only there can both components of the velocity be estimated. The ADCP measurements will provide in situ measurements of water velocity and eddy momentum flux with which to determine the accuracy of the satellite estimates over temporal scales of 10 days and longer. The in situ measurements will also allow us to determine the degree to which the surface satellite estimates represent the upper 150 to 200 m of the ocean. In a similar way, temperature and current data from the mooring will be used to calculate horizontal heat transports, which can be used to verify estimates made from AVHRR and altimeter data at the surface and to check the relation between surface estimates and deeper values. The satellite data can then be used with greater confidence to investigate heat and momentum transports in the large-scale California Current over the 3- to 5-year TOPEX period.

The altimeter data can also aid in the analysis of the momentum budget at the buoy, if it is located at a crossover, to provide an estimate of the surface pressure gradient at the buoy location every 10 days. If the pressure gradient is expressed as ageostrophic velocity, the momentum budget in the upper-ocean boundary layer can be written in the form of a geostrophic velocity defect law. For instance, the u component would be

$$\frac{\partial u}{\partial t} = f(v - v_g) - \vec{V}_H \cdot \nabla u - w \frac{\partial u}{\partial z} + \frac{\partial}{\partial z} \left(K_m \frac{\partial u}{\partial z} \right)$$

with a similar expression for the v component. This assumes a deviation in the surface boundary layer from an interior, geostrophic velocity. The geostrophic velocities, calculated from the altimeter, will help to identify the depth

at which the measured ADCP velocity best represents the geostrophic velocity associated with the external pressure gradient. This will allow the ageostrophic dynamics to be examined in a manner not previously possible.

Finally, location of the current and meteorological measurements under the TOPEX crossing will allow verification of geostrophic currents calculated from the altimeter data and some checks on the various environmental corrections applied to the altimeter data. The data from the experimental current meter may help in verifying the currents calculated from the altimeter early in the mission. Measurements of surface pressure and water velocity at the buoy will allow checks on the corrections applied to the altimeter data for surface pressure (from atmospheric models) and tides (by comparing the measured velocities in the tidal frequency band to tidal models). Measured wind speed will allow evaluation of the wind-speed estimate made from altimeter data. Humidity data will allow a partial check of the integrated water vapor estimated from the multichannel microwave sensor and verification of algorithms used to estimate surface humidity from satellite estimates of total water vapor.

M. University of Colorado Verification Plans: G. H. Born

The University of Colorado Center for Astrodynamic Research (CCAR) has developed a floating GPS buoy that was funded under a National Science Foundation grant. The prototype buoy capability to measure sea level and waves was demonstrated at Scripps' pier near La Jolla, California, in 1989. A more robust buoy, capable of withstanding the open-ocean environment of Point Conception, was tested at Platform Harvest in an experiment in August 1990. In November 1991, a modified version of this buoy was deployed on an ERS-1 ground track off the coast of San Diego, California. In collaboration between JPL and the University of Texas, data from this experiment are being processed to determine the altimeter bias. After the TOPEX/POSEIDON launch, the buoy will be deployed on the ground track, possibly at a point where ground tracks intersect. Laser tracking of the satellite that supports the Point Conception activities will also provide orbit tracking data for the Cortes Bank location.

Other verification activities will include the comparison of TOPEX/POSEIDON altimeter data with results obtained from GEOSAT and ERS-1.

N. University of Texas Global Verification Activities: B. Tapley and C. K. Shum

As by-products of their science investigations, Tapley and Shum of the University of Texas, Center for Space

Research, will produce data for several parameters pertinent to the TOPEX/POSEIDON verification efforts. These investigators will monitor height bias and its drift, verify the altimeter time bias, and determine a scale factor to $H_{1/3}$ to correct the altimeter height measurement. The monitoring of height bias and its possible drift will be performed through the long-time averaging of altimeter-inferred mean sea surface. An altimeter time bias estimate will be obtained from crossover analysis. The determination of scale to $H_{1/3}$ will be performed using both direct altimeter and crossover analysis. If extra funding becomes available (e.g., NASA fellowship), the group will calibrate wet tropospheric corrections from the TMR. The requisites for this added work include meteorological data and radiosondes or upward-looking water-vapor radiometer data.

O. Altimeter Transponder Experiment: E. J. Christensen and J. Powell

An altimeter transponder is an instrument that merely reflects a radar pulse transmitted by an altimeter back to the altimeter. A passive device analogous to an optical corner cube would do; however, it is more practical to reflect the signal electronically.

Prototype altimeter transponders have been developed for use with ERS-1 and TOPEX/POSEIDON. John Powell has developed two such units, one for the Rutherford Appleton Laboratory (RAL) and one for NORDA. Powell is currently using these transponders to conduct experiments with ERS-1 (Powell, 1986). Two additional transponders are being developed by NASA, one at JPL through the TOPEX/POSEIDON Project, and the other at Interferometrics, Inc., through the NASA Small Business Innovation Research program. The interferometrics instrument is a highly experimental, adaptive transponder that can be more readily deployed than a classical transponder. All of these units can also be adapted to future altimetric missions (e.g., TOPEX Follow-ON and EOS).

For the ERS-1 experiment, the RAL, NORDA, and JPL units were deployed. They were referenced to positions in the vertical obtained by GPS techniques. Tropospheric and ionospheric measurements were made with the GPS during the overpass so that proper range corrections can be applied. Three measurement objectives were sought:

- (1) First Half of the Commissioning Phase: demonstration of new radar altimeter techniques suited to geodetic measurement, relative transponder-to-transponder and transponder-to-ocean height comparisons, and intercomparison of these techniques and GPS measurements.

- (2) Second Half of the Commissioning Phase: assessment of the residual errors on the orbits provided for ERS-1 at the 3-cm level for an arc length of 0.4 of a revolution.
- (3) First Ice Phase: assessment of the accuracy with which altimetric measurements to the surface of the high Antarctic Ice Plateau may be used as a relative pass-to-pass orbit altitude reference, and continued assessment of the residual errors on the orbits provided for ERS-1 at the 3-cm level, for an arc length of 0.4 of a revolution.

The ERS-1 experiments are expected to establish the technology needed to develop a global sea-level monitoring network. It is proposed that the initial system consist of a minimum of two transponders deployed along a 1000- to 2000-km segment of the TOPEX/POSEIDON satellite ground track. Each site will be equipped with a transponder, GPS receiver, and a WVR. The GPS receiver will be used to provide an independent measurement of the vertical coordinates of the transponders relative to a fiducial reference. They will also be used to calibrate the ionospheric and tropospheric corrections to the altimeter height. It has been suggested that GPS data by itself can be used to construct a simple homogeneous layer model for the troposphere and thereby effect an accurate range correction. This approach will be verified through the use of WVRs and radiosonde data.

During the TOPEX/POSEIDON verification phase, one set of experimental equipment will be placed on a tower, small island, or platform at sea. A tide gauge will also be included as part of the instrument complement. An integral part of the analysis will be the evaluation of the EM-bias and ionospheric delay using transponder data. This will be accomplished by comparing sea level as measured by the altimeter to sea level as measured by the transponder and tide gauge. This will require a detailed analysis of the altimeter tracker response when a transponder signal is present, removal of the transponder signal from the ocean-surface waveform, and retracking of both the ocean waveform and the transponder returns to obtain independent estimates for both measurements. The orbit, ionospheric, and tropospheric effects are common to both measurements, so the difference between the two is attributable to EM-bias and instrument noise. Note that this comparison can be made at both K-band and C-band, so the frequency-dependent nature of EM-bias and ionospheric delay can also be evaluated.

In addition, transponders will be deployed at TOPEX/POSEIDON and ERS-1 crossing points so that an

intercomparison of altimeter data from each mission can be performed. SDR data within ± 5 minutes of each transponder overflight will be required for this work.

P. TOPEX/POSEIDON Sea-Level Variability In the Pacific Ocean Validated With In Situ Data Collected by the Japan Meteorological Agency: A. Shibata, K. Nishiyama, and M. Amino

1. Introduction

Recently, microwave sensors aboard satellites have been used satisfactorily in observing such oceanographic parameters as sea-level variability and sea-surface wind. The most important sensor among several microwave sensors for oceanographic observations is an altimeter, and it has been shown that sea-level variability can be retrieved with errors of about 5 cm from the U.S. Navy Geosat Altimeter. In August 1992, TOPEX/POSEIDON will be launched, and sea level is expected to be obtained with much higher accuracy than was obtained from Geosat. We will retrieve sea-level variability in the Pacific Ocean by applying a collinear method to the TOPEX/POSEIDON data in near real time with access to the Jet Propulsion Laboratory (JPL) computer through the Internet.

As the IGOSS Specialized Oceanographic Center (SOC) for the Pacific Ocean, the Marine Department of the Japan Meteorological Agency (JMA) collects sea temperature and current data and disseminates products on a real-time/operational basis by radio facsimile and a 10-day bulletin. Sea surface currents are analyzed subjectively every 10 days and the paths of major currents are shown as in Figure V-6. The analysis is also the basis of our forecast. The data used now are (1) currents measured by ship drift, ADCP, and drifters; (2) in situ surface and subsurface temperatures; and (3) satellite SST images. Though the data observed within a month are used, data coverage in regions and currents like the Kuroshio Extension, warm and cold rings, and tropical currents are insufficient.

We will develop the method of real-time use of the TOPEX/POSEIDON data for analysis and forecast of ocean conditions conducted by the JMA, and also we will validate the TOPEX/POSEIDON products with in situ data collected by the JMA.

2. Data Analysis and Validation

We will adopt a collinear method to retrieve sea-level variability from the TOPEX/POSEIDON data. This method has several merits in operational works: (1) easy-to-adjust orbital errors, (2) easy-to-find possible errors of the TOPEX/POSEIDON data, and (3) accuracy even in ocean areas

adjacent to lands. The last merit is most valuable for data analysis in the western Pacific. Sea-level variability will be obtained every day for each resolution of the TOPEX/POSEIDON, and grid data will be calculated at 10-day intervals.

The sea-level variability will be mapped in the scale common with in situ data, and compared with those in situ data collected by the JMA. The sea-level variability will be superimposed upon the previous current analysis to detect such features as the shift of current paths and the movement of eddies. In the northwestern Pacific Ocean around the Japanese islands, there are enough oceanic in situ data to validate the TOPEX/POSEIDON variability.

3. Areas

The TOPEX/POSEIDON sea-level variability will be produced in two areas, and they are shown in Figure V-7.

Area 1 (the western Pacific) is bounded by

west: 100°E
east: 180°
south: 10°S
north: 50°N

Area 2 (the central and eastern Pacific in the tropics) is bounded by

west: 150°E
east: 70°W
south: 20°S
north: 20°N

In the first year we will produce sea-level variability in area 1. We will produce sea-level variability in area 2 in the second or third year.

4. Data Delivery

We will send both magnetic tapes and maps of the TOPEX/POSEIDON variability and also maps of in situ data to JPL every month (i.e., data from October 1 through 31 will be sent by the end of November).

5. Tasks

Dr. Shibata of the Meteorological Research Institute (MRI) analyzed the Geosat data and developed the collinear method. The staff of MRI will receive the TOPEX/POSEIDON data through the NASA Science Internet. Mr. Amino and his assistants at the JMA will analyze and validate the TOPEX/POSEIDON data and send the products to JPL. The MRI is an associate institute of the JMA.

6. The TOPEX/POSEIDON Team In Japan

This work will be done by the JMA group as a part of activities of the TOPEX/POSEIDON Team in Japan; the proposed title of this work is "Ocean Transports of Mass, Heat, and Salt in the Western North Pacific." The Principal Investigator is Professor K. Taira of the University of Tokyo, but he will be replaced by Professor S. Imaewaki of Kyushu University in April 1992.

7. Future Work

It will be possible to obtain the geoid along the ground track of the TOPEX/POSEIDON in some areas where the axis of oceanic currents moves seasonally or interannually. To do this, it will be necessary to analyze the 2- or 3-year TOPEX/POSEIDON radial-ephemeris data with an error of about 10 cm. After the geoid is determined, our next work will be to obtain the oceanic current in near real time, in which orbital errors will be adjusted again by applying the collinear method.

Q. Evaluation of TOPEX/POSEIDON Data Over Nonocean Surfaces: C. S. Morris, D. A. Imel, P. S. Callahan, E. J. Christensen, and S. K. Gill

1. Overview

Although the TOPEX/POSEIDON Mission is designed to maximize the science return from the ice-free ocean, the potential exists to utilize these data over land, lakes, rivers, and sea ice. The utility of altimeter data over nonocean surfaces has been demonstrated with Seasat, Geosat, and, currently, ERS-1. For the purposes of verification, nonocean surfaces provide a useful contrast that can be utilized to investigate the stability of the altimeter and the response of the tracker.

2. Participants

The participants include but are not limited to

Charles S. Morris	JPL
David A. Imel	JPL
Philip S. Callahan	JPL
Edward J. Christensen	JPL
Stephen K. Gill	NOAA/NOS

3. Regions of Interest

Geosat data are currently being reviewed to select the most interesting regions to study. Likely candidates for case studies include

Lakes:	The Great Lakes, Lake Tanganyika
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Rivers:	Amazon
Sea Ice:	Antarctic (primarily)
Land:	Great Salt Lake Desert, Central Australia, Amazon Rain Forest

The global dataset will be used to obtain statistics on tracker response to nonocean surfaces.

4. Analyses

A variety of analyses will be conducted using TOPEX/POSEIDON SDR and (T)GDR data. The altimeter data will be compared with NOAA/NOS tide gauge readings in the Great Lakes. Repeat track and waveform retracking analyses will be performed for selected lakes, rivers, and land areas to investigate the stability of the altimeter-based altimeter range measurements and σ_0 values. Tracker response statistics will be compiled globally and individual case studies of loss of lock over different surfaces will be reviewed.

5. Reporting Results

The results obtained in this study will be reported at postlaunch JVT meetings and will be submitted for publication to an appropriate refereed journal.

R. Analysis of TOPEX/POSEIDON Data Over Land, Rivers, Lakes, and Streams: H. Frey

H. Frey at GSFC has submitted a Letter of Intention to join the JVT by performing analyses on altimeter data taken over land and inland bodies of water.

S. CNES Quick-Look Analysis: P. Y. Le Traon

CNES quick-look activities will be based mainly on work by PIs and CoIs. A TOPEX/POSEIDON data processing chain has been set up to make their job easier and to produce results more quickly. CNES PIs and CoIs involved in quick-look activities will regularly receive validated, preprocessed TOPEX/POSEIDON data (orbit-error corrections and calculation of sea-level anomaly (SLA) relative to a cycle or a mean).

The chain will also provide global products such as SLA variability maps, spectral analyses, along-track visualization of $H_{1/3}$, and wind speed.

During our talks with CNES PIs and CoIs starting in the summer of 1991, we listed and described the quick-look products that could be obtained in the year after the launch. The PIs agreed to supply them as quickly as possible.

These products are briefly described in Table V-2, which shows the production lead time in months after the first TOPEX/POSEIDON cycle.

The PIs will, of course, be fully involved with promotion. The list is a guideline only, as the products will certainly evolve when the first sets of TOPEX/POSEIDON data are analyzed, with the surprises we can (fortunately!) expect.

Table V-1. Summary of the Principal Investigator's activities.

Experiment focus	Leader	Objectives	TOPEX/POSEIDON data required	Time frame
Bass Strait	N. White	On-site height verification	POD and IGDR	During and after the verification phase
Mediterranean Sea	F. Barlier	Regional orbit and orbit and MSS validation	POD, DORIS, laser, and IGDR	During and after the verification phase
Around UK	P.L. Woodworth	Local SSH and POD verification	IGDR	During and after the verification phase
Tyrrhenian Sea		Wind speed and $H_{1/3}$ validation; tropospheric correction, SSH validation	IGDR pass files IGDR	November 1992 Time slot in 1993
Sea ice, lakes, rivers, and deserts		Global tracker statistics and characteristic performances	Full SDR cycles	During and after the verification phase Feb 1993 experiment
Sea-state bias	L.-L. Fu	Sea-state bias evaluation	3 days of SDR	During and after the verification phase
Quick-look products		Gridded fields of SSH, wind, and $H_{1/3}$	IGDR pass files	
SEMAPHORE, northeast Atlantic	L. Eymard	SSH validation, wind and wave validation, and tropospheric correction	IGDR pass files, IGDR and full cycle of POSEIDON data	Jun-Jul 1993 Oct-Nov 1993
Nordic Sea dynamics	L.H. Pettersson	SSH validation and geoid estimate	IGDR	1992 to 1995
Sea-level validation	R. Cheney	Timing bias, sea-state bias, geophysical correction assessment	IGDR	During and after the verification phase
Western equatorial Pacific	J. Picaut	SSH validation; atmospheric effects	IGDR	During the verification phase Nov 1992-Feb 1993

Table V-1 (contd)

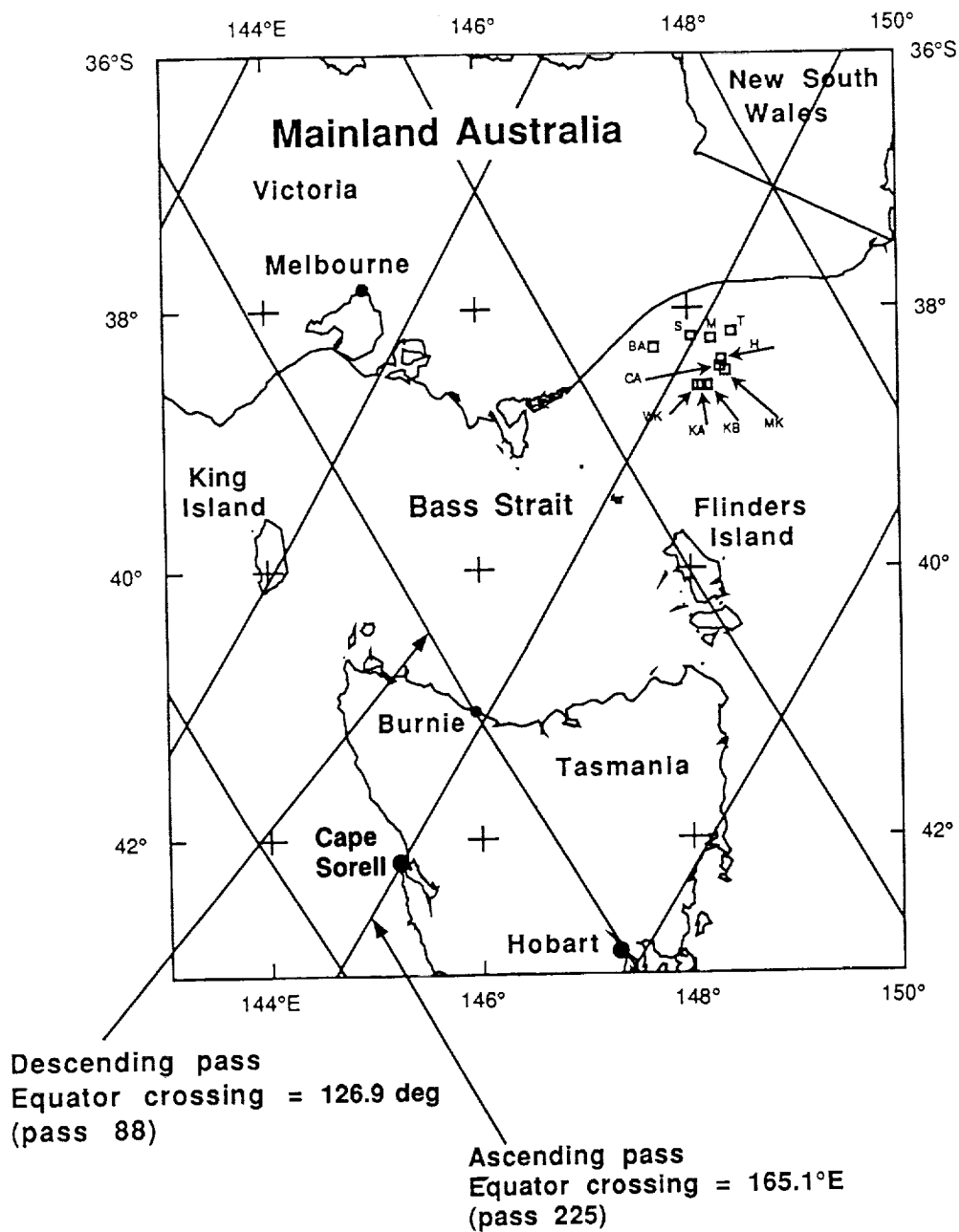
Experiment focus	Leader	Objectives	TOPEX/POSEIDON data required	Time frame
Activities around Japan	J. Segawa	POD validation and MSS validation	IGDR	During and after the verification phase
Hawaii sea-level center contribution	G.T. Mitchum	Regional sea-level verification	IGDR	During the verification phase
Kuroshio region	J. Mitchell	Sea-level quick-look products	IGDR	During the verification phase
California Current System	P.T. Strub	Sea-level eddy transport and geostrophic currents	IGDR	For 1 year starting in Aug 1992
GPS buoy experiment	G.H. Born	Altimeter calibration	Laser data IGDR	During the verification phase
Global verification	B. Tapley	Height bias and drift timing bias	IGDR	During the verification phase
Altimeter	E.J. Christensen	Altimeter transponder experiment, EM-bias, and ionospheric delay validation	Selected SDRs	During and after the verification phase
Sea-level variability	A. Shibata	Altimeter near Japan	IGDR pass files	During the verification phase and possibly following
Nonocean surfaces	C.S. Morris	Evaluation of data over nonocean surfaces	IGDR pass files; selected SDRs	During the verification phase and possibly following
Land, lakes, and rivers	H. Frey	Evaluation of data over nonocean surfaces	IGDR pass files; selected SDRs	During the verification phase and possibly following
Quick-look analysis	P.Y. LeTraon	Quick-look products	IGDR pass files	During the verification phase

Table V-2. TOPEX/POSEIDON Quick-look products from CNES PIs and CoIs.

Person in charge	Product	Lead time
C. Le Provost	Tide signal in English Channel	1 month
A. Cazenave	Overlaying mean TOPEX/POSEIDON track on existing mean surface	1 and 3 months
S. Arnault	Large-scale altimeter maps and comparison with models of Tropical Atlantic	3 months
P. De Mey	Comparison of TOPEX/POSEIDON data in northeast Atlantic with assimilated ERS-1 fields	3 months
J. M. Lefevre	Comparison of altimetric $H_{1/3}$ and wind with models (Mediterranean or North Atlantic)	3 months
J. F. Minster	Monitoring strong altimetric signals (rivers)	4 months
C. Périgaud	Global altimetric variability (20 days to 100 days)	4 months
C. Le Visage	Monitoring mesoscale structures in north-east Atlantic	4 months
C. Périgaud	Monitoring mean level and transport of main currents in Indian and Pacific Oceans	4 months
P. Vincent	Altimeter calibration/validation from Lampedusa	4 to 5 months
J. Picaut	Comparison with drifting buoy data and current-meter moorings in tropical Pacific	6 months
M. Gründlich	$H_{1/3}$ in Agulhas current	6 months
S. Arnault	Preliminary study of waves in tropical Atlantic	7 months
P. Mazzega	Maps of main ocean tides by global inversions	7 months
C. Millot	Analysis of Algerian eddies from ERS-1 and TOPEX/POSEIDON data comparison with AVHRR measurements	7 months
P. Queffelecoulou	Sea state and storm surges in North Atlantic	6 months/12 months
Y. H. Park	Variability of Antarctic Circumpolar Current in Crozet Basin	6 months and June 1993
A. Cazenave	Adjusting long wavelengths of mean sea surfaces to TOPEX/POSEIDON profiles	6 months/12 months
C. Provost	Animation of Brazil/Falklands confluence region	7 months

Table V-2 (contd)

Person in charge	Product	Lead time
J. Verron	Assimilation of TOPEX/POSEIDON altimeter data in model of North Atlantic	7 months
P. Vincent	Animation of tide solutions in Pacific and Antarctic Circumpolar Current	9 to 12 months
J. Verron	Assimilation of TOPEX/POSEIDON altimeter data in a PE model of confluence region	12 months
J. Verron	Special issue of Oceanologica Acta (JASO meeting)	End of 1992
S. Arnault	Comparison of TOPEX/POSEIDON data with Cither experiment data	
P. Tarits	Comparison of TOPEX/POSEIDON data with Babas Station in Canary Basin	July 1993
J. Picaut	Accurate validation of altimetric sea level in open ocean	July 1993
C. Le Visage	Comparison of TOPEX/POSEIDON data with SEMAPHORE-93 data	August 1993



Bass Strait oil platforms

Snapper	S	38°13'S	148°02'E	Kingfish A	KA	38°36'S	148°08'E
Marlin	M	38°14'S	148°13'E	Kingfish B	KB	38°36'S	148°11'E
Halibut	H	38°24'S	148°19'E	West Kingfish	WK	38°36'S	148°06'E
Cobia A	CA	38°27'S	148°18'E	Barracouta A	BA	38°18'S	147°41'E
Mackerel	MK	38°29'S	148°21'E	Tuna	T	38°11'S	148°25'E

Figure V-1. The Bass Strait region.

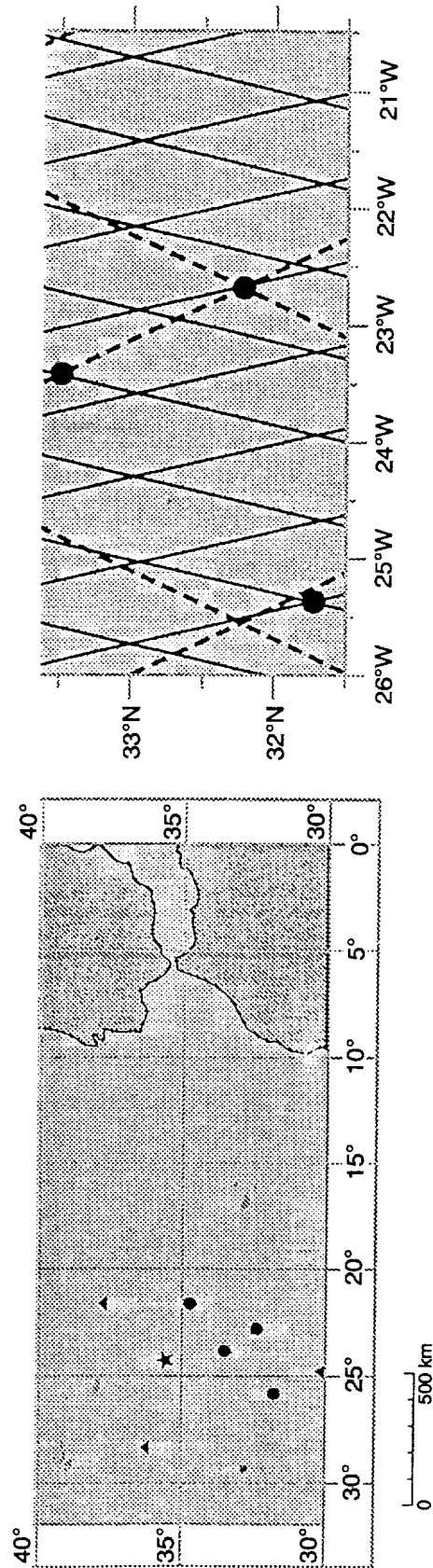


Figure V-2. SEMAPHORE experiment study area southeast of the Azores. Location of the current-meter moorings (large dots), the meteorological mooring (star), and the sound sources (triangles) are also shown. Solid lines on the right represent ERS-1 satellite tracks and dotted lines the TOPEX/POSEIDON satellite tracks.

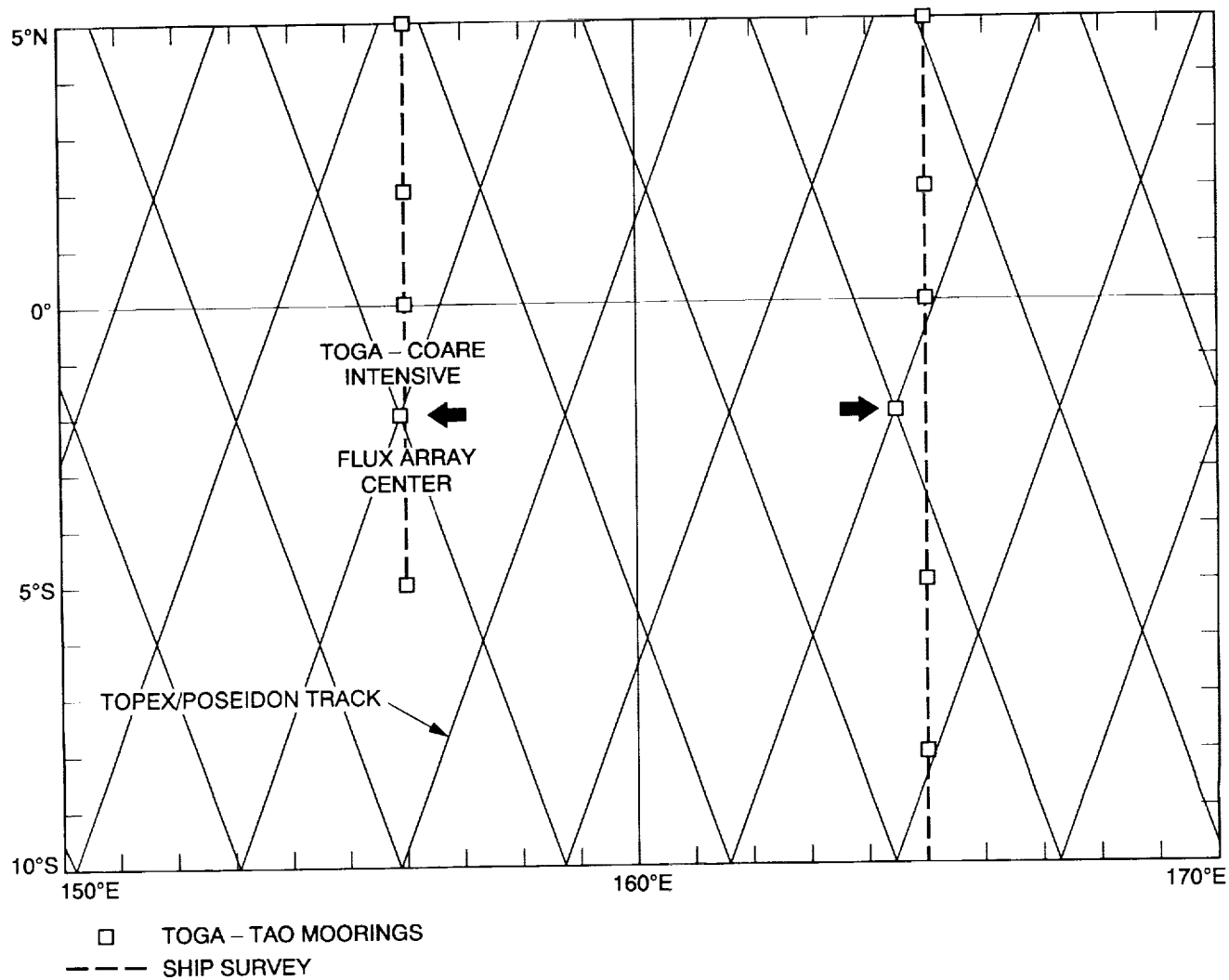


Figure V-3. Location of the proposed work. The arrows indicate the two moorings just at the TOPEX/POSEIDON crossovers.

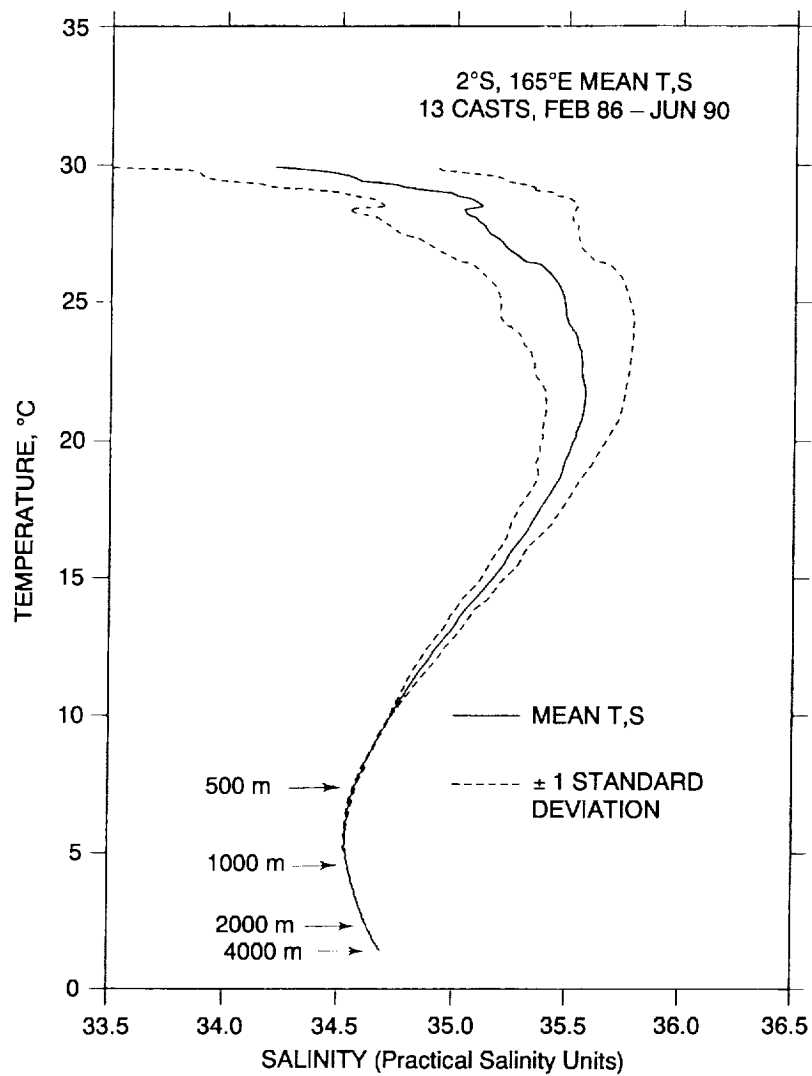


Figure V-4. Mean and standard deviation of 13 CTD casts taken at 2°S, 165°E on a T,S diagram. The largest salinity dispersion appears in the first 500 m.

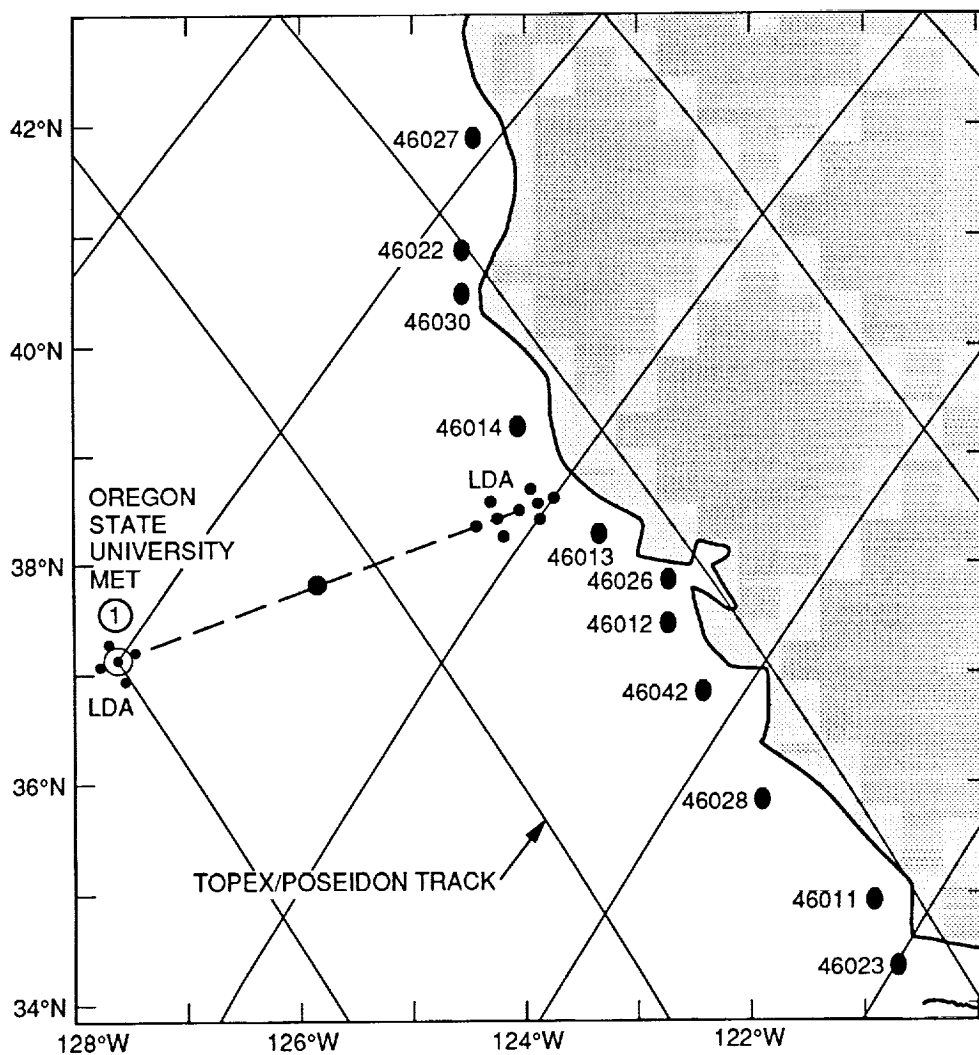


Figure V-5. Location of the meteorological buoy in relation to TOPEX altimeter tracks (curved diagonal lines), NDBC coastal buoys, a large-scale current-meter array, and local dynamics arrays (LDA). The meteorological buoy with upper-ocean sensors would be located at the center of the offshore LDA. The solid circles are current-meter moorings and the open circle at the offshore LDA is the meteorological upper-ocean buoy.

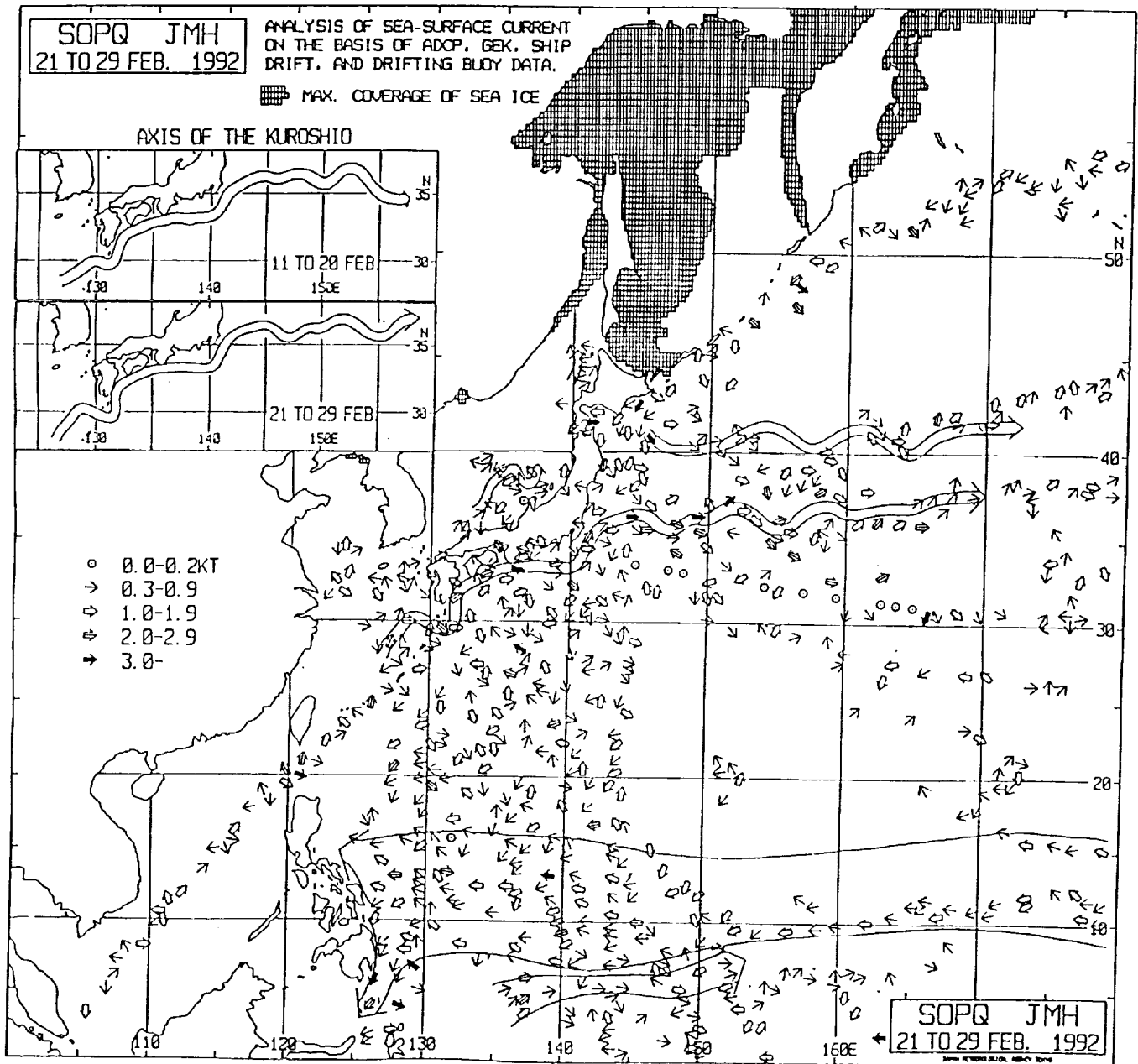


Figure V-6. Analysis of sea-surface current as one JMA product.

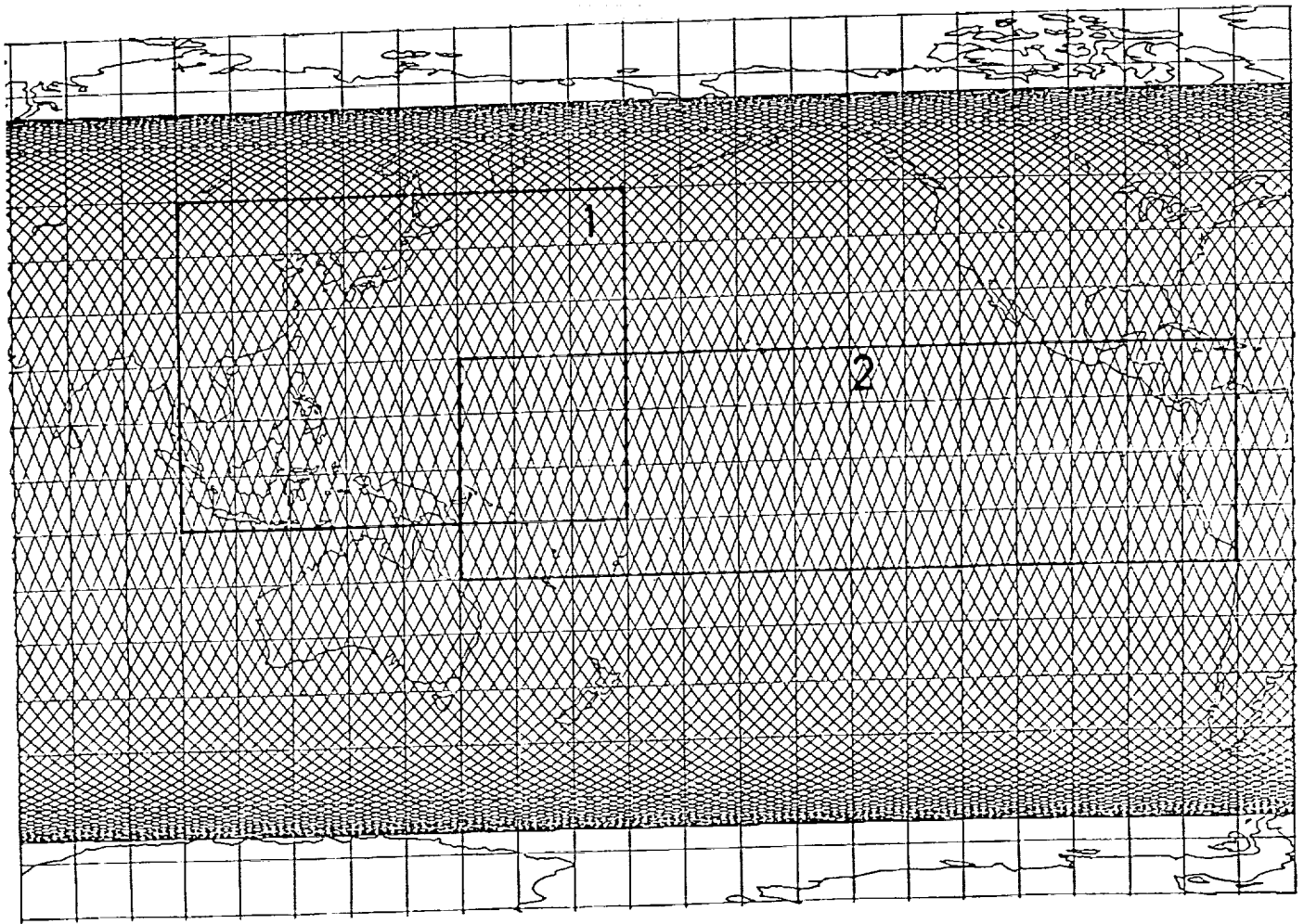


Figure V-7. Areas of sea-level variability as a JMA product and the TOPEX/POSEIDON ground track.

VI. Data Analysis and Distribution

Two levels of analyses will be performed during the course of the mission: quick-look and routine. The primary purpose of the quick-look analyses is to assess the project's data system, whereas the routine analysis will be used to assess the project's data product.

A. Quick-Look Analyses

The quick-look analyses will be a near-real-time activity conducted primarily for diagnostic purposes. These analyses will be useful for the early detection of problems that may occur within the measurement and verification systems. It is intended that these analyses help in resolving problems between successive overflights of the verification sites in particular, and provide some lead time for global and regional analyses in general. The requirements and design objectives for this activity are the following:

- (1) Pass files of IGDR data and SDR data will be made available to the Joint Verification Team (JVT) as soon as the project can make them accessible. A working assumption is that this will be done on a best-efforts basis within 3 to 5 days of a pass for a nominal mission.
- (2) The JVT will use the pass files to conduct analyses at the primary verification sites, the secondary verification sites, and the regional campaign sites. The JVT will also use these data to perform global statistical analyses.
- (3) The data listed in Table VI-1 will be made available to the JVT as soon as the responsible JVT member can make them accessible (within 12 to 20 calendar days).
- (4) Results of the analyses and related diagnostic information will be reported through a JVT mailbox.
- (5) This activity will continue throughout the verification phase of the mission and at a more leisurely pace through the end of the mission.

B. Routine Analysis

A complete and thorough scientific analysis of the Project IGDRs and GDRs (i.e., the project products) will be conducted. The results of this analysis will be formally

reported to the project. The requirements and design objectives for this activity are the following:

- (1) During the verification phase of the mission, this analysis will be conducted using the IGDRs and selected SDR data files distributed to the Principal Investigators. The project GDRs and selected SDR data files will be used for the remainder of the mission (CNES has not made a firm commitment to participate in the activity during the observational phase of the mission).
- (2) Analysis will be conducted on a cycle-by-cycle basis. The NASA and CNES teams will deliver all finalized data sets (e.g., in situ data and ephemerides) for a given cycle within 20 days after the end of the cycle under consideration. These data sets will be retained by the project in an archive.
- (3) Updates to such sets as the in situ data and ephemerides are expected up to the time the analysis for a given cycle is complete.
- (4) Results of the routine analysis will be reported through a JVT bulletin board and summarized at the Postlaunch Verification Meeting.

C. Verification-Data Distribution Plans and Schedule

The NASA and CNES verification datasets that will be exchanged and distributed to members of the JVT are summarized in Table VI-1. These datasets will include the data collected from the Point Conception and Lampedusa verification sites (see Sections III and IV) and ancillary information, such as tracking data (laser, DORIS, and GPS), short-arc orbits, model results, and closure results. In addition, both TOPEX and POSEIDON IGDR pass files and a limited number of SDR files will be made available to approved members of the JVT. Note that the distribution of the in situ data and IGDR pass files is independent of (and should not be confused with) the standard distribution of the (I)GDRs to all SWT members.

To have access to either the in situ data or the IGDR pass files, permission must be obtained from one of the JVT cochairman: E. Christensen or Y. Menard. A short proposal (in letter form), which outlines the use of the data, is required prior to obtaining access to these data sets.

1. IGDR Pass Files

Each IGDR pass file includes IGDR data for one-half revolution ("a pass"). The pass files generated will be distributed to those JVT members who require the IGDR data as near to real time as possible. Although the IGDR pass files should be exactly the same as the IGDRs that will be delivered to the SWT, it is possible that the IGDR pass files may differ from the final IGDRs and thus are not intended for general distribution. Researchers are expected to replace the IGDR pass files with the corresponding IGDRs when they become available.

The IGDR pass files will be made available to approved members of the JVT by the Physical Oceanographic Data Active Archive Center (PODAAC) for NASA JVT members and by AVISO for CNES JVT members. Both PODAAC and AVISO plan to establish read-only computer access for these data. Researchers will be provided with an account that permits them to log on to either the PODAAC or AVISO computer and download the pass files that they require. Neither PODAAC nor AVISO plan to actively distribute (send) IGDR pass files to users.

Both PODAAC and AVISO schedules depend on the pass files being made available by the project. In the anticipated PODAAC schedule for the NASA IGDR pass files, the project will make these files available within 5 days after the data are taken. PODAAC will post the pass files within 1 day of obtaining them and will maintain the pass files for at least 20 days. After that period, the IGDRs that replace the pass files should be available. Availability of the CNES IGDR pass files to NASA JVT members is expected to be on a similar (or perhaps slightly delayed) schedule. The AVISO schedule for posting IGDR pass files is expected to be similar to PODAAC's schedule.

2. SDR Files

Selected SDR files will be made available to JVT members by AVISO and PODAAC in a manner similar to that for the IGDR pass files. Because of the significantly larger volume of the SDR files, only a few files of special interest for verification activities will be made available during each cycle.

3. In Situ Data

Both NASA and CNES will collect in situ data at their respective verification sites. In addition, laser data obtained during verification site overflights, derived short-arc orbits, closure results, and model results will be also be generated in support of CAL/VAL analyses. NASA and CNES will exchange these data and ancillary information.

The NASA in situ data for the Point Conception verification site for a given overflight will be maintained for a period of time on the TOPEX Ground System (TGS) VAX computer. Read-only access to these data will be provided to CNES. In a similar manner, CNES will provide NASA read-only access to their in situ data sets, which will reside on a UNIX workstation. It has been agreed that the in situ datasets, in preliminary form, will be made available on the 13th day after an overflight and, in final form, on the 20th day after an overflight. "Preliminary form" is defined as data that has been checked, but may still require some modification or correction. "Final form" is defined as data that has been thoroughly checked and is not expected to require any further modification or correction. The in situ data will not necessarily be available to the other party prior to the 13th day after the given overflight. This flow of data is shown in Figure VI-1.

Table VI-1. Data and information exchange for joint verification.

Item	CNES (Lampedusa)	NASA (Pt. Conception)
Altimeter data		
Quick-look	CNES IGDR pass files Selected CNES SDR data	NASA IGDR data pass files Selected NASA SDR data
Routine (verification phase)	CNES IGDRs ERS-1 intercomparisons	NASA IGDRs ERS-1 intercomparisons
Routine (observation phase)	CNES GDRs ERS-1 intercomparisons	NASA GDRs NASA IGDR data pass files Selected NASA SDR data
In situ data ^a		
Tide gauge data	Bottom Pressure Gauges (4) (2 at Lampedusa, 1 at Lampione, 1 at Marettimo) GPS buoy(s)	NOAA Acoustic or bubbler CU Pressure Gauge GPS buoy
Meteorological data	Air temperature Wind speed Barometric pressure Relative humidity	Air temperature Wind speed (from buoys) Barometric pressure Relative humidity
Wind/waves	GPS buoy(s)	Buoy(s) Pressure gauge
Site-SLR survey	GPS Local surveys	GPS Local surveys

^a All in situ data will be "processed" data in the sense that the instrument data have been properly corrected, smoothed, and transformed to standard engineering units. Some of the data may be condensed to a time series in proximity of an overflight.

Table VI-1 (contd)

Item	CNES (Lampedusa)	NASA (Pt. Conception)
Water vapor	PORTOS radiometer ATSR radiometer JPL J-series radiometer Radiosondes	JPL J-Series radiometer
Ionosphere	GPS DORIS	GPS DORIS
Tracking data		
SLR	SLUM (Milo) MTLRS1 (Lampedusa)	MOBLAS4 (Quincy) MOBLAS 8 (Monument Peak) MLRS (Fort Davis) TLRS4 (Mazatlán)
DORIS	All data in view	
GPSDR CG-LRA correction LRA correction		All data in view GSFC POD Team GSFC POD Team
Short-arc ephemerides		
SLR and DORIS	GRGS format IFAG format	P-File and POE format (JPL) GEODYN POE format (GSFC)
GPSDR		P-File and POE format (JPL)
Preliminary POEs		
DORIS	ZOOM or POE format (CNES)	

Table VI-1 (contd)

Item	CNES (Lampedusa)	NASA (Pt. Conception)
SLR		GEODYN POE format (GSFC)
TDRSS/S-band		Definitive OOE
Models		
Sea level	Mediterranean Gulf of Sicily	
Wind and waves	Mediterranean Gulf of Sicily	
Ionospheric correction	Global	
Results ^b		
Closure analysis	CNES, NASA, supplemental sites	NASA, CNES, supplemental sites
Global analysis	Stats, crossing arc, repeat track	Stats, crossing arc, repeat track
Ionospheric correction	NASA ALT, DORIS, GPS	NASA ALT, DORIS, GPS
Tropospheric correction	WVR, TMR	WVR, TMR
TMR calibration		WVR, radiosondes

^b Quick-look results will be reported using a computer mailbox. Routine results will be reported using a computer bulletin board and will be summarized at SWT verification meetings.

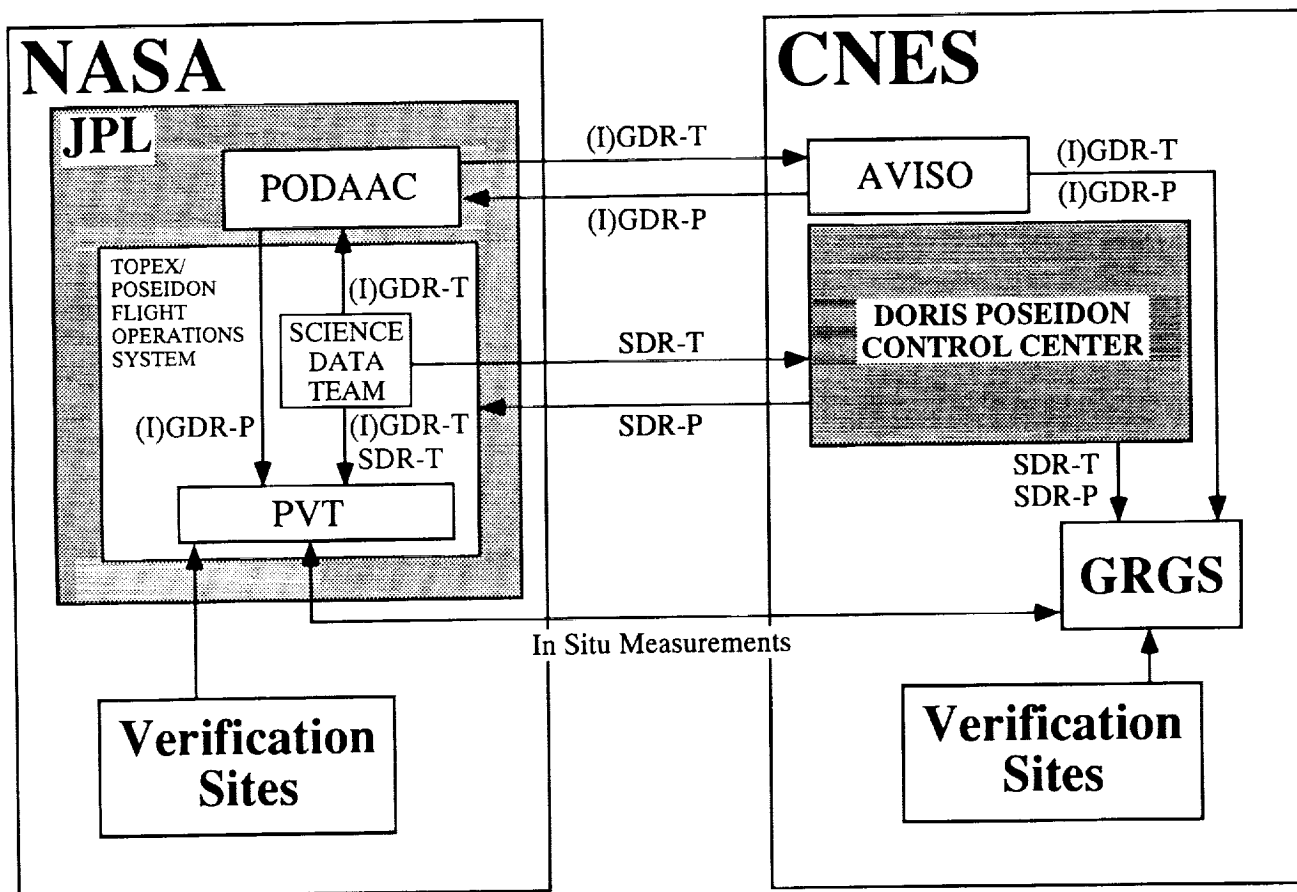


Figure VI-1. NASA and CNES verification data flow.

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VIII. Acronyms

ADCP	Acoustic Doppler Current Profiler	CSIRO	Commonwealth Scientific and Industrial Research Organization
AGC	automatic gain control	CTD	conductivity/temperature/depth
ALT	Dual-Frequency Radar Altimeter	CTDP	Centre de Traitement DORIS/POSEIDON
ARI	ONR's Accelerated Research Initiative	CU	University of Colorado
ATSR	Along-Track Scanning Radiometer	DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
AVHRR	Advanced Very High Resolution Radiometer	ECMWF	European Center for Medium Range Weather Forecast
AVISO	Analysis and Validation of Satellite Oceanographic Data	EISCAT	European Incoherent Scatter Radar System
BPR	bottom pressure gauge	EM	electromagnetic
CAL/VAL	calibration-validation	EOS	Earth Observing System
CDDIS	Crustal Dynamics Project Data Information Center	EPSHOM	Etablissement Principal de la Service Hydrographique et Oceanographique de la Marine
CDSLR	Crustal Dynamics Project Satellite Laser Ranging	ERM	extended repeat mission
CEPMMT	Centre Européen pour les Prévisions Météorologiques à Moyen Terme	ERS-1	European Remote Sensing Satellite
CERGA	Centre d'Etudes et de Recherches Géodynamiques et Astronomiques	GDR	Geophysical Data Record
CLS-ARGOS	Compagnie Collecte Localisation Satellites ARGOS	GEODYN	GSFC's POD software
CNES	Centre National d'Etudes Spatiales	GPS	Global Positioning System
CNET	Centre National d'Etudes de Télécommunications	GPSDR	Global Positioning System Demonstration Receiver
CNRM	Centre National de Recherches Météorologiques	GRGS	Groupe de Recherches en Géodésie Spatiale
CNR-ENEA	Consiglio Nazionale delle Ricerche-ENEA	GSFC	Goddard Space Flight Center
COARE	TOGA's Coupled Ocean-Atmosphere Response Experiment	IAPG	Institute of Astronomical and Physical Geodesy (University of Munich)
CoI	Co-Investigator	IFAG	Institut Für Angewandte Geodäsie
CP	calibration point	IFM	Institut für Meereskunde
CRPE	Centre de Recherche en Physique de l'Environnement	IFREMER	Institut Français de Recherche pour l'Exploitation de la Mer

IGDR	Interim Geophysical Data Record	NOAA	National Oceanic and Atmospheric Administration
IGN	Institut Géographique National	NOS	National Ocean Service
IMET	improved meteorological measurements from buoys and ships	ONR	Office of Naval Research
IMG	Institut de Mécanique de Grenoble	OOE	operational orbit ephemeris
IMST	Institut de Mécanique Statistique de la Turbulence	pdf	probability density function
INMARSAT	International Maritime Satellite	PI	Principal Investigator
INSU	Institut National des Sciences de l'Univers	PMEL	NOAA's Pacific Marine Environmental Laboratory
IOP	Intensive Observation Period	POD	precision orbit determination
ISDGM	Istituto per lo Studio della Dinamica delle Grandi Masse	PODAAC	Physical Oceanographic Data Active Archive Center
JMA	Japan Meteorological Agency	POE	precision orbit ephemeris
JPL	Jet Propulsion Laboratory	POL	Proudman Oceanographic Laboratory
JVP	Joint Verification Plan	PVT	Precision Orbit Determination and Verification Team
JVT	Joint Verification Team	QG	quasi-geostrophic
LA	Laboratoire d'Aérodynamique	RACS	rotating antenna C-band scatterometer
LDA	Local Dynamics Array	RESSAC	Restitution du Spectre de la Surface par Analyse Circulaire
LRA	Laser Retroreflector Array	RGO	Royal Greenwich Observatory
MET	meteorology	ROWS	Radar Ocean Wave Spectrometer
METEO-France	French Meteorology Office	SAO	short-arc orbit
MRI	Meteorological Research Institute	SBS	Software Based Systems Company
MSSL	mean sea surface level	SDR	Sensor Data Record
MTR	miniature temperature recorder	SHOM	Service Hydrographique et Océanographique de la Marine
NAC	Norwegian Atlantic Current	SLA	sea-level anomaly
NASA	National Aeronautics and Space Administration	SLR	satellite laser ranging
NCAR	National Center for Atmospheric Research	SLUM	Station Laser Ultra Mobile
NDBC	National Data Buoy Center	SOC	Specialized Oceanographic Center
NGWLMS	Next Generation Water Leveling Measuring System	SOD	satellite orbit determination

SSALT	single-frequency solid-state radar altimeter	TMR	TOPEX Microwave Radiometer
SSH	sea-surface height	TOGA	Tropical Ocean and Global Atmosphere Programme
SST	sea-surface temperature	UMASS	University of Massachusetts
SWT	Science Working Team	VLBI	very long baseline interferometry
T,S	temperature, salinity	WCRP	World Climate Research Programme
TAO	Terre Atmosphère Océan	WFF	Wallops Flight Facility
TEC	total electron content	WOCE	World Ocean Circulation Experiment
TEMPO	Tyrrhenian Eddy Multi-Platform Observations	WVR	water-vapor radiometer
TGS	TOPEX Ground System	XBT	expendable bathythermograph
TLRS	Transportable Laser Ranging System	ZOOM	CNES POD software system

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15. Supplementary Notes					
<p>16. Abstract</p> <p>TOPEX/POSEIDON is a satellite mission that will use altimetry to make precise measurements of sea level with the primary goal of studying global ocean circulation. The mission is jointly conducted by the United States' National Aeronautics and Space Administration (NASA) and the French space agency, Centre National d'Etudes Spatiales (CNES). The current plans call for a launch of the satellite in August 1992. The primary mission will last 3 years, and provisions have been made to extend the mission for an additional 2 years. The mission has been coordinated with a number of international oceanographic and meteorological programs, including the World Ocean Circulation Experiment and the Tropical Ocean and Global Atmosphere Programme, both of which are sponsored by the World Climate Research Programme. The observations of TOPEX/POSEIDON are timed to provide a global perspective for interpreting the in situ measurements collected by these programs and in turn will be combined with observations of other satellites to achieve a global, four-dimensional description of the circulation of the world's oceans.</p> <p>In the autumn of 1987, an international team of 38 Principal Investigators was selected to participate in the mission. These scientists have been working closely with the TOPEX/POSEIDON Project to refine the mission design and science plans. During the first 6 months after launch, a number of these investigators will join with the project to conduct a wide range of oceanographic and geophysical investigations using the TOPEX/POSEIDON data. The purpose of these investigations is to demonstrate the scientific utility of the mission to the international scientific community.</p>					
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